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RECENT PROGRESS IN THE DEVELOPMENT OF PNEUMATIC DISPATCH TUBES.

BY B. C. BATCHELLER.

As you all know, pneumatic dispatch tubes are not an invention of recent date; that is to say, their commercial application began forty-five years ago. Every one is more or less familiar with them, as they are used in large retail stores for the transmission of cash from the various counters to the cashier's desk. Many large office buildings are equipped with them for dispatching messages from one office to another. The Western Union Telegraph Company has used them since 1876 in New York City, to transmit their telegrams from one office to another, it being found more expeditious than the telegraph.

The United States usually takes the lead in the application of mechanical devices, but in the uses of pneumatic dispatch tubes we are behind our European neighbors.

London, Paris, Berlin and Vienna for years have had their pneumatic tube systems for transmitting telegrams between the central and branch post-offices. The service is not confined to the large cities, for Liverpool, Brussels and other smaller cities are now equipped with this modern method of transportation.

There is much misconception of the size, capacity, length and use of the tube systems of Europe, for which the daily press is principally responsible. I have seen it stated that Paris and Berlin are connected by pneumatic tubes. It goes without saying that such a statement is untrue. Many people believe that mail is sent through the tubes, but that is also untrue, for the tubes are not large enough for that purpose. They are used only for the transmission of telegrams and messages. The largest tubes in London are only 3 inches in diameter, while those of Paris and Berlin are about 2½ inches. *Fig.* 7 shows the Berlin and London carriers,

The first tube was laid in London in 1853 by the Electric International Telegraph Company, under the direction of Mr. Josiah Latimer Clark. It was 1½ inches in diameter, and extended from Founder's Court to the Stock Exchange, a distance of 220 yards. Year by year the system has been extended, until now the entire business section of the city is covered by a network of tubes radiating from the General Postoffice and terminating in the numerous sub-post-offices. (In England the telegraph is controlled by the Government, and the telegraph offices are in the post-offices.) The tubes are of lead, encased in cast iron and laid in pairs for dispatching in opposite directions. Berlin has a similar system to that of London, but in Paris the tubes are laid in circuits with several stations on a circuit. The carriers are forwarded in trains from one station to another around the circuit.

It is not the purpose of this paper to describe these European systems in detail, but I refer to them to give some idea of the state of the art up to 1893.

Admitting that the European cities have gotten the start of us in point of time, we are bound not to be beaten

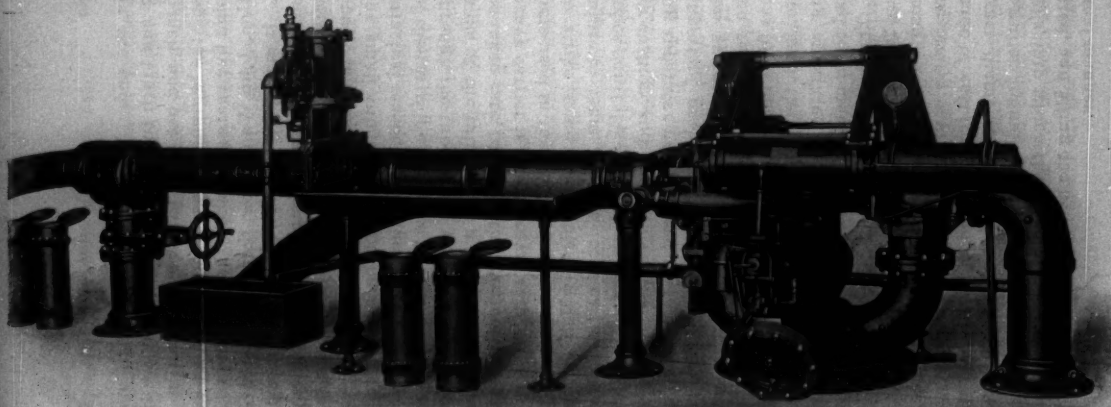

FIG. 1.—Sending apparatus and open receiver, Produce Exchange Line, Main Post-office, New York City.

in the end. While they continue to operate their small 2- and 3-inch tubes for telegrams only, we begin by building 6-inch, and use them to transport mail in large quantities, and the beginning was made in our own city of Philadelphia five years ago, when the first line was opened by the Hon. John Wanamaker, then Postmaster-General.

It may seem to many of you like a simple step, from 3-inch to 6-inch tubes, but I will say from experience that the small tubes were no guide or help to us in building larger ones. The methods of operation and apparatus used with the small tubes could not be applied to the larger. The principal reason for this lies in the greatly increased weight of the cartridge, or, as we term it, carrier, that is dispatched through the tube. The weight causes friction against the walls of the tube and is a storehouse for energy that must be taken care of when the carrier is brought to rest. A heavy carrier is like a heavy train on a railway. The carriers used in the small tubes are stopped by allowing them to strike some solid object, which can be done without injury to them, but the large carriers used in 6-and 8-inch tubes must be brought to rest gradually by means of an air cushion, and this involves the use of automatic receiving apparatus not required in the small tubes. The more important problems that had to be solved in designing the system of 6-inch tubes were the sending apparatus, the receiving apparatus, the carrier and the tubes. This was for a line of two stations. When intermediate stations are used the problems of switches and automatic receiving apparatus to select carriers at their destined stations had to be met.

The first double line of tubes built in Philadelphia was laid from the main Post-office, Ninth and Chestnut Streets, along Chestnut Street to the sub-post-office, now located in the Bourse, a distance of about 3,000 feet. The tubes were made of cast-iron water-pipe, bored upon the interior to an exact diameter of $6\frac{1}{8}$ inches. The lengths were joined together by making a counter bore at the bottom of the bells, into which the machined end of the adjoining length fitted, and filling the bell with yarn and lead caulked in the usual manner.

Where it became necessary to turn corners seamless brass tubing was used, bent to a radius of not less than 6 feet. The tubes were simply buried in the ground, one above the other, at a depth varying from 3 to 10 feet, depending upon the location of other underground construction, such as water and gas pipes, conduits, sewers, etc.

The line was, and still is, operated by an air compressor located in the basement of the main Post-office. This compressor is of the duplex type, built by the Clayton Air Compressor Works, and does not differ, except in relative size of cylinders, from the compressors on the market for general purposes. It develops about 25 horse-power and compresses about 800 cubic feet of free air per minute to a pressure of 7 pounds per square inch. The dispatching and receiving apparatus is located on the main floor of the Post-office near the cancelling machines and in the rear room of the sub-post office in the basement of the Bourse.

The tubes are in operation from nine o'clock in the morning until seven in the evening, excepting the noon hour.

The air current flows continuously from the main Post-office to the Bourse through one tube and returns to the main Post-office through the other, thus forming a loop with the return end connected to the suction pipe of the compressor at the Post-office. There is an opening in the tube to the atmosphere near where it is connected to the compressor, so that the entire circuit contains air at a pressure above the atmosphere.

It is a pressure system rather than a vacuum system as these terms are commonly understood.

Carriers occupy sixty seconds in transit from the Post-office to the Bourse and fifty-five seconds for the return trip. They can be dispatched at six-second intervals or ten per minute in each direction.

This 6-inch tube has been in operation for five years and is doing good service to-day.

Not content with this, the promotors of this enterprise decided to go one step further and build an 8-inch tube.

The second line was laid in New York City between the main Post-office and branch Post-office P, in the Produce

Exchange Building. It is similar in method of operation to the first Philadelphia line, but somewhat longer, the distance between stations being about 4,000 feet. Some improvements were made in the sending apparatus, utilizing the air

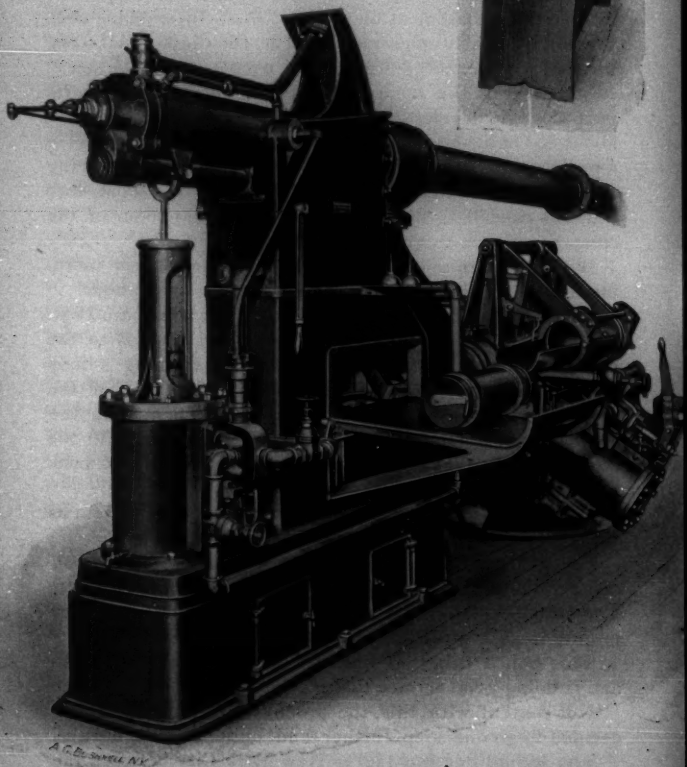

FIG. 2.—Sending apparatus and closed receiver, Produce Exchange Line, Postal Station H, New York City.

pressure to do what was formerly done by manual labor. See *Figs. 1* and *2*.

When this Produce Exchange circuit was opened for business the construction of a second circuit was well under way in New York, extending from the main Post-office to branch Post-office H, on Forty-fourth Street near the Grand Central Depot, a distance of 3½ miles, with three intermediate stations on the line; at Postal Station D, Third Avenue and Eighth Street; Madison Square Postal Station and Postal Station F, at Third Avenue and Twenty-eighth Street.

The main line of this circuit was opened February 11th, but the receiving apparatus for the intermediate stations is not yet completed. This is the longest circuit built thus far. The inside diameter of the tubes, like the Produce Exchange circuit, is 8½ inches. There are two tubes, one for dispatching up-town and the other down-town. They are operated by air compressors, located one at the Post-office and the other at Forty-fourth Street. The time of transit of the carriers in either direction is about seven minutes. The air pressure at the compressors is 13 pounds.

During the autumn of last year a circuit of 8-inch tubes was constructed in Boston between the main Post-office and the North Union Railway Station, a distance of about 4,500 feet, or a little less than 1 mile. This is similar in all respects to the Produce Exchange line in New York. It is used to transport the outgoing mail from the post-office to the trains, and the incoming mail from the trains to the Post-office.

On Thursday, April 7th, a circuit of tubes between the main Post-office and the Pennsylvania Railroad Station at Broad Street, in this city, was formally opened for the transportation of mail to and from the trains. A little later there is to be an intermediate station established at the Reading Terminal. The tubes are laid from the Post-office through Chant Street to Tenth Street, up Tenth Street to Filbert Street, and out Filbert Street to the Pennsylvania Station.

Another circuit is partially constructed between the main Post-office in New York and the main Post-office in Brooklyn, by way of the Brooklyn Bridge.

The total length of 8-inch tubing in all these circuits is a little more than 17 miles. This has all been manufactured and laid under ground, with the exception of the incompleted part of the Brooklyn Bridge line, since August 1st, last year.

THEORY.

A current of air may be made to flow through a tube by either pumping the air in at one end under a pressure above that of the atmosphere, or by exhausting the air, thereby reducing its pressure below that of the atmosphere. In either case it is the difference of pressure at the two ends of the tube that causes the air to flow. Both methods are used in operating the London and Paris tubes, and both are used in the cash systems of our large retail stores, but all of our large tubes are operated by compressing the air so that the air-pressure in the tubes is at all points above that of the atmosphere. The determining of which system shall be adopted depends largely upon circumstances.

In the operation of short lines of small tubes, all of the machinery and apparatus can be concentrated at one point by using compressed air in the outgoing tubes and rarified air in the incoming tubes.

So far as power is concerned, the exhaust method is more economical, because nearly all the power is consumed in overcoming the friction of the air in the tube, and this friction varies directly with the density of the air.

There are several reasons why the compressed-air method of operation is better: first, if there are any leaks in the tubes, and they happen to be laid in the wet ground, water will be drawn into the tubes when the air is exhausted, while it will be kept out if the air-pressure is above the atmospheric; second, air-cushions, for checking the speed of the carriers when they arrive at a station, are much more efficient and effective with compressed than rarified air; third, cylinders and pistons used to operate sending and receiving apparatus can be made smaller when compressed air is used.

There are two methods of using the current of compressed or rarefied air in the operation of a line, and these

are termed the intermittent and constant methods. The first consists in storing compressed air in a suitable tank, or by exhausting the air from a tank; then when we wish to dispatch a carrier we place it in the tube and connect the tube with the tank by opening a valve. As soon as the carrier arrives at the distant end of the tube the valve is closed, and the air soon ceases to flow. When a long interval of time elapses between the dispatching of carriers, this is the most economical method of operation; but if carriers have to be dispatched frequently, a great deal of time would be lost in starting and stopping the air current throughout the whole length of the tube. Under these conditions the second method, which consists in maintaining a constant current of air in the tube, and in having the carriers inserted and ejected at the ends of the tube without stopping the current of air for any appreciable length of time, is much more rapid and efficient. This latter method is the one used in the operation of all our large tubes. The current of air flows continuously all day, and the carriers containing mail are swept along like boats in a rapidly-flowing stream. The analogy is quite perfect. The boats obstruct the flow of water and check its speed but little. In order to compute the speed with which the boats will pass from one point to another, we have only to know the speed of the stream between those points when no boat is in it. The presence of the boats does not change the speed appreciably. So it is with carriers in a pneumatic tube; the air flows nearly as rapidly when a carrier is in a tube as when there is none. The friction of the carrier against the inner surface of the tube creates a slight drag, but it checks the speed of the air only a little. Therefore, in order to know the speed with which a carrier will be transported from one station to another, we need only to know the velocity with which the air flows through the tube when no carrier is present.

Let us assume a simple case of an 8-inch tube 1 mile long, connected at one end to a tank in which a constant air pressure of 10 pounds per square inch is maintained, the other end of the tube being opened to the atmosphere.

I have constructed a diagram showing the air pressure at all points along the tube (see *Fig. 3*). The abscissæ represents lengths of tube in feet and the ordinates air pressure

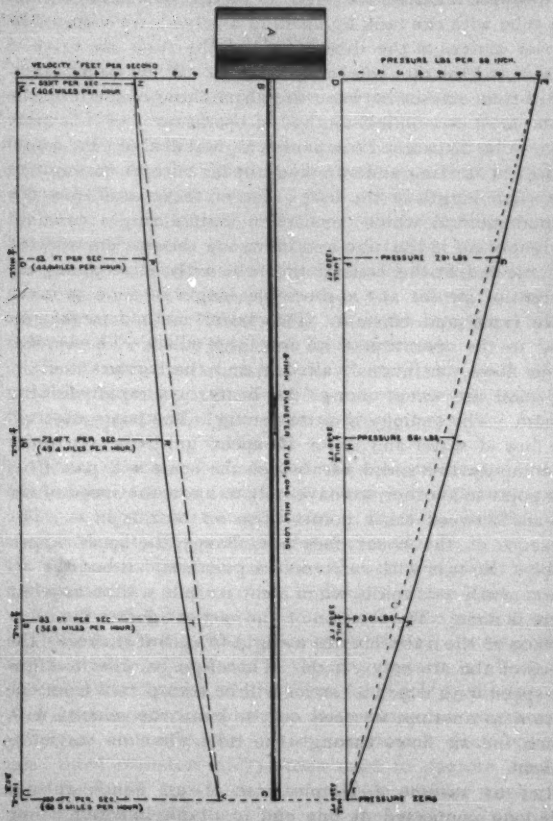

FIG. 3.—Diagram showing the pressure and velocity of the air in a pneumatic tube.

above the atmospheric in pounds per square inch. At the tank end the pressure is 10 pounds, at the open end zero, and at the quarter, half and three-quarter mile points 7·91, 5·61 and

3·01 pounds respectively. It will be observed that the pressure curve is slightly convex upwards. This is due to the expansion of the air in the tube. The pressure curve of the flow of water in a pipe is a straight line. The fall of pressure along the tube is analagous to the fall of level in a flowing stream or to the fall of potential along a wire in which a current of electricity is flowing.

I have constructed another diagram showing the velocity of the air at every point along the tube. The abscissæ are lengths of tube in feet, the ordinates velocity of the air in feet per second. The velocity at the tank end, quarter, half and three-quarter mile points and at the opened end is 59·5, 65, 72, 83 and 100·4 feet per second, respectively. It will be noticed that the velocity of the air increases as it flows along the tube, and that it increases more rapidly as it approaches the open end of the tube. The increase of velocity is due to the expansion of the air as it flows along the tube, and the expansion results from the fall of pressure. The mean of all the ordinates gives us the mean velocity, which enables us to compute the time of transit of a carrier through the tube. We can also determine from this velocity curve the time of transit between any two points on the tube which may represent stations.

From the velocity with which the air is discharged from the open end of the tube we compute the quantity of air that must be compressed per minute. The quantity of free air and the initial pressure enables us to compute the horse-power required to maintain the current of air constantly flowing. Of course, there are numerous factors which enter into these computations which are only determined by experiment and experience, such, for example, as the quantity of air that escapes from the tube at the sending and receiving apparatus; the fall of pressure of the air in flowing around bends and through the apparatus; the efficiency of the air compressor, etc.

The temperature of the air, from the instant it enters the compressor until it is discharged at the open end of the tube, is an interesting and important factor in the theory of pneumatic transmission. Since pressures above 25

pounds per square inch are seldom used, the air cylinders of the compressors are not water-jacketed, hence the air is heated by compression to a temperature found by measurement to be above the theoretical amount that we should expect from thermodynamic formulæ. The reason for this will be understood when we remember that the incoming air is heated by contact with the hot walls of the cylinder. When air is compressed to 7 pounds per square inch, it leaves the compressing cylinder at about 160° F. We should expect much of this heat to be soon lost by conduction and radiation through the walls of the tube, and as the air flows through the tube, constantly expanding, it would not be unreasonable to expect considerable reduction in temperature by the time it reached the open end of the tube—a temperature considerably below that of the atmosphere. Experience teaches us that after leaving the compressor the temperature of the air falls rapidly, and that the temperature in the tubes underground is almost constant, being about that of the surrounding earth. The compression may be considered as adiabatic and the expansion as isothermal with very little error.

The atmosphere at all times contains more or less moisture in a state of vapor, and its capacity for water vapor varies directly with its temperature; that is to say, the higher the temperature the more water vapor will the air contain, and *vice versa*. The temperature of the air in the tubes is frequently and usually lower than the atmosphere out-of-doors, consequently it often happens that moisture is deposited upon the interior of the tubes. The quantity is never very great, but sometimes the carriers come out of the tube coated upon the exterior with a thin film of moisture. We use the same air over and over, thereby avoiding drawing into the tube large quantities of moisture-laden air.

Having thus briefly discussed the theory of the flow of air in long tubes, we will now consider some of the necessary mechanical details. Keeping in mind our 8-inch tube, 1 mile long, connected to a tank of compressed air at one end and open to the atmosphere at the other, thereby main-

V. 18

taining a constant flow of air through the tube. In order to utilize this tube and air current for the transportation of mail or merchandise, we must have some means of inserting carriers containing the material to be transported into the tube, without the escape of air. In other words, we must have some form of sending apparatus or transmitter. This might be accomplished by having a section of the tube

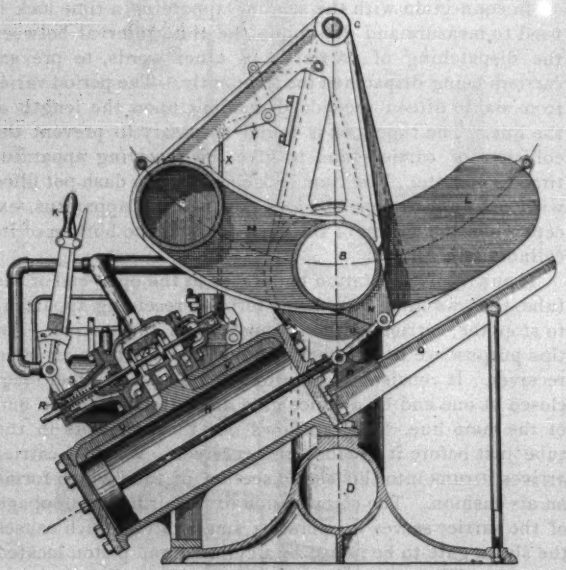

FIG. 4.—Cross-section of sending apparatus.

with valves at each end to stop the flow through this section and conduct it through a by-pass. A carrier could then be inserted into this section of tube and the valves be turned to their normal position. Or, what we find to be more practical is to have a section of the tube that can be swung out of line with the main tube to receive a carrier

and then swung back into line again. This is the form of sending apparatus that we use in all our 8-inch tubes. The section of tube is swung by a cylinder and piston operated by the air pressure taken from the tube (see *Figs. 1* and *4*.) The attendant has only to place a carrier in the sending apparatus and pull a lever. By using two swinging sections of tube, one of which is always in line with the main tube, the apparatus is ready at all times to receive a carrier.

In connection with the sending apparatus, a time lock is used to measure and determine the time interval between the dispatching of carriers; in other words, to prevent carriers being dispatched too frequently. The period varies from six to fifteen seconds, depending upon the length of the line. The time lock is found necessary to prevent the collision of carriers and to give the receiving apparatus time to operate. The time lock consists of a dash-pot filled with oil and arranged to lock the sending apparatus, except when the piston of the dash-pot is at the bottom of its cylinder (see *Fig. 5*).

If our receiving station be located at the open end of the tube, then we must have some form of receiving apparatus to stop the carriers without shock when they arrive. For this purpose we have in our system what we term an open receiver. It consists of a section of tube about 4 feet long, closed at one end by a sluice gate and attached to the end of the main line. The air flows out through slots in the tube just before it reaches the receiver. When a carrier arrives it runs into this closed section of tube which forms an air cushion. The compression of the air by the stoppage of the carrier serves to operate a small valve, which causes the sluice gate to be raised by a cylinder and piston located above it. When the gate raises the carrier is forced out on to a receiving table, the pressure in the tube being just sufficient to do this. The gate is automatically closed after the carrier has been discharged (see *Fig. 1*).

If our receiving station be located at any other point on the line of the tube we cannot use this form of open receiver, for the pressure in the tube is so high, as shown on the diagram, that the air would escape with great force, hence we must

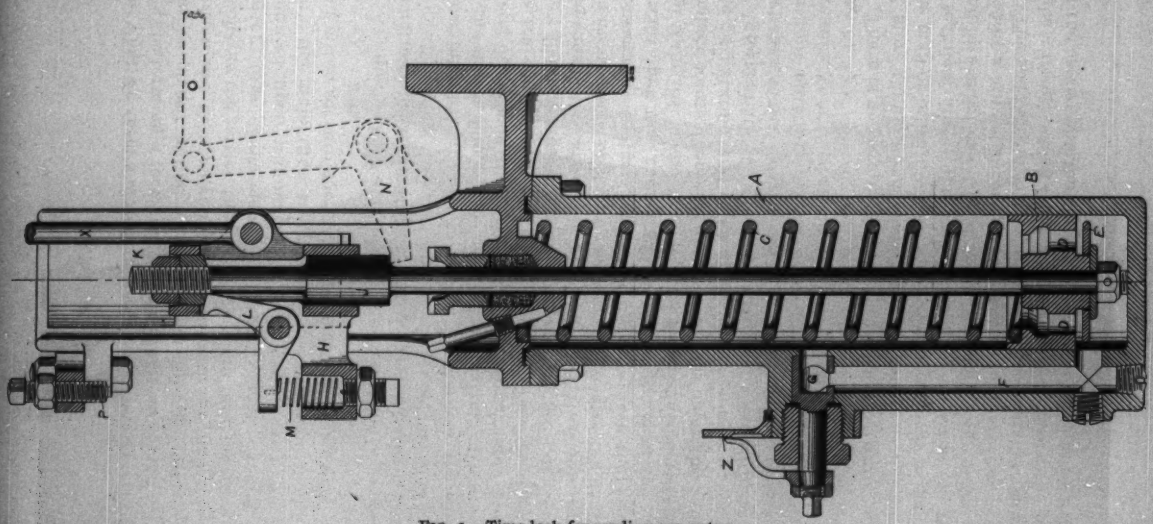

FIG. 5.—Time-lock for sending apparatus.

use what we term a closed receiver, consisting of a section of tube forming a receiving chamber and air cushion that can be placed in line with the main tube to receive the carrier, and then moved out of line with the main tube to discharge the carrier, the end of the main tube being closed during this displacement. The receiving chamber is mounted upon trunnions, and is swung out and into line with the main tube automatically by means of a cylinder and piston set into operation by the arrival of a carrier (see *Fig. 2*).

At intermediate stations on the main line of tubes we sometimes place an automatic receiving apparatus that will stop all carriers passing through the tube, and discharge those intended for that station, while all others are sent on in the tube. This is accomplished by placing various sized metal discs upon the front end of the carriers and having electric contact points at each of the stations set at graduated distances apart to correspond with the sizes of discs on the ends of the carrier. When a carrier arrives at a station where its disc is of the proper diameter to span the distance between the contact points, and thereby close the electric circuit, then that carrier will be discharged from the tube; but if the disc is too small to span the distance between the contact points, then the carrier will pass on in the tube to the next station, and so on.

Intermediate stations are usually supplied with cut-out switches, so that carriers can be sent directly past the station without entering it. These switches are moved by air pressure, controlled electrically from the nearest station (see *Fig.* 6).

There is no part of this system that has been the object of more thought and study than the carrier that contains the mail or other material to be transported. It is made of a seamless steel tube 23½ inches long, closed at the front end by a sheet metal head and buffer, and closed at the rear end by a hinged cover provided with a lock (see *Fig.* 7).

The body of the carrier is about an inch smaller than the tube through which it travels, the space between the body of the carrier and the surface of the tube being filled by two

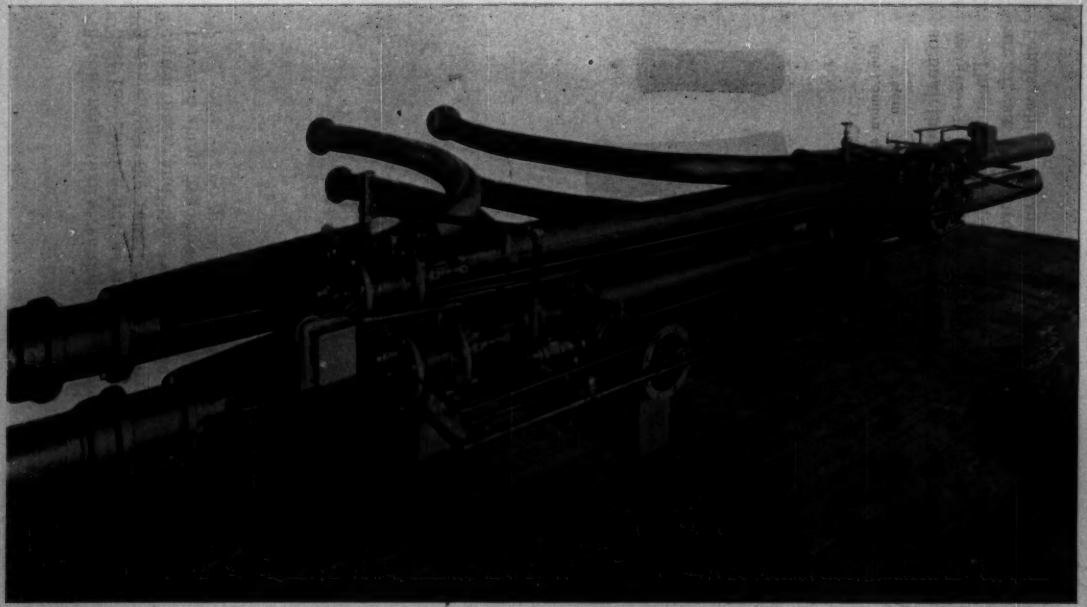

FIG. 6.—Set of cut-out switches for eight-inch pneumatic tubes.

fibrous rings that serve not only to prevent the escape of air past the carrier, but as wearing surfaces to slide on the lower side of the tube. These bearing rings are made of cotton fiber, and they will endure until the carrier has traveled about five thousand miles, when they become worn

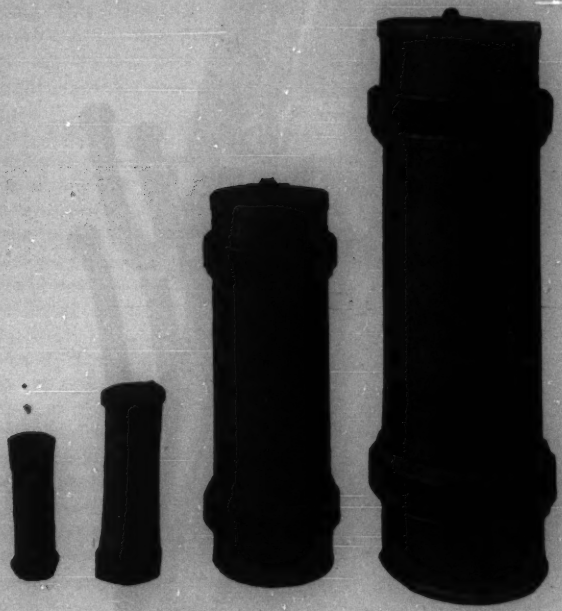

FIG. 7.—(1) Carrier used in the Berlin system; (2) Largest carrier used in the London system; (3) Six-inch carrier used in the first Philadelphia system; (4) Eight-inch carrier used in New York and Boston.

so small that they have to be replaced by new ones. A carrier weighs 13¾ pounds, and will contain 600 ordinary letters.

The tubes used in all the circuits thus far constructed are of cast iron bored accurately upon the interior, except bends, which are made of seamless brass tube. The iron

tube is cast in 12-foot lengths, with a bell upon one end, similar to water and gas pipes. A counter bore is turned in the bottom of each bell, into which the machined end of the adjoining length fits closely. The joints are made by yarn and lead caulked in the usual manner.

Where short bends have to be made in the tube for the

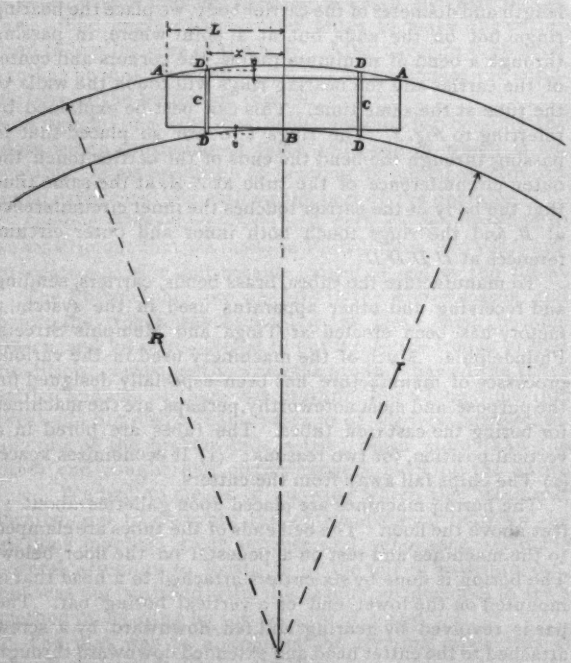

FIG. 8.

purpose of turning corners in the streets, entering buildings, etc., brass tubing is used bent to a radius of twelve times the diameter of the tube, or a radius of 8 feet for an 8-inch tube. A uniform radius is always used, for it facilitates manufacture.

In order to maintain a uniform and circular cross-section of the tubes during the process of bending, they are filled with resin.

The location of the bearing rings on the body of a carrier also has an important relation to the bends in order to give a carrier of maximum capacity. Having determined the length and diameter of the carrier body, we place the bearing rings not on the ends, but at a point where, in passing through a bend of minimum radius, the corners and center of the carrier and the bearing rings will touch the walls of the tube at the same time. This can best be explained by referring to *Fig. 8.* The rings *C C* are so placed that in passing through the bend the ends of the carrier touch the outer circumference of the tube at *A A*, at the same time that the body of the carrier touches the inner circumference at *B*, and the rings touch both inner and outer circumferences at *D D D D*.

To manufacture the tubes, brass bends, carriers, sending and receiving and other apparatus used in the system, a factory has been erected at Tioga and Memphis Streets, Philadelphia. Much of the machinery used in the various processes of manufacture has been especially designed for the purpose, and most noteworthy, perhaps, are the machines for boring the cast-iron tubes. The tubes are bored in a vertical position, for two reasons: (1) It economizes space. (2) The chips fall away from the cutters.

The boring machines are placed upon galleries about 11 feet above the floor. The bell ends of the tubes are clamped to the machines and rest on a pedestal on the floor below. The boring is done by six cutters attached to a head that is mounted on the lower end of a vertical boring bar. The bar is revolved by gearing and fed downward by a screw attached to the cutter head and extended downward through the center of the tube being bored. The feed screw does not revolve, but is drawn downward by a nut attached to the pedestal on which the tube is supported. The nut is revolved by gearing and a rope belt driven from the machine above. When a tube is placed in the boring machine the feed screw is pulled up through it and attached

to the cutter head. The boring bar simply serves to revolve the cutter head and not to guide it. The cutter head is guided by four hardwood blocks that fit the finished bore of the tube closely. The pull of the feed screw also helps to keep the cutter head in place. The cutters are flat pieces of steel, with a cutting edge at 45° with the axis of the tube. The angle of the cutter tends to make the cutter head follow the core of the tube. After the bore is finished another head is attached to the bar, which makes the counter bore at the bottom of the bell.

A special machine has been designed for bending the brass tubes, consisting of three rolls, one of which is adjustable. This operation of bending is one that requires much experience and skill on the part of the operator.

Locating Obstructions.—You will, perhaps, be interested in an experiment that we made in Philadelphia two years ago to locate a carrier that became lodged in one of the tubes.

The Philadelphia line was laid in the winter season, and before the trench was back-filled the loose earth became frozen, and we were obliged to put it into the trench in that condition; consequently, when the ground thawed the tubes settled and one of them was broken. For a long time this break did not obstruct the passage of carriers, but eventually one of the broken ends settled down more than the other and caught one of the carriers, blocking the entire line. We had no means of knowing where the break was located, and to excavate the entire distance between the stations involved great expense and annoyance. I made several attempts to locate it by the fall of pressure, etc., but was not satisfied with the results, so decided to try a method of locating by the velocity of sound.

The plan was to disconnect the terminal apparatus at one of the stations, fire a pistol into the tube, and note the time that elapsed between the discharge of the pistol and the return of the sound as an echo reflected back from the obstructing carrier; then, knowing the velocity of sound, a simple calculation would give us the distance from the station to the carrier.

I had a rough chronograph constructed, using a pulley

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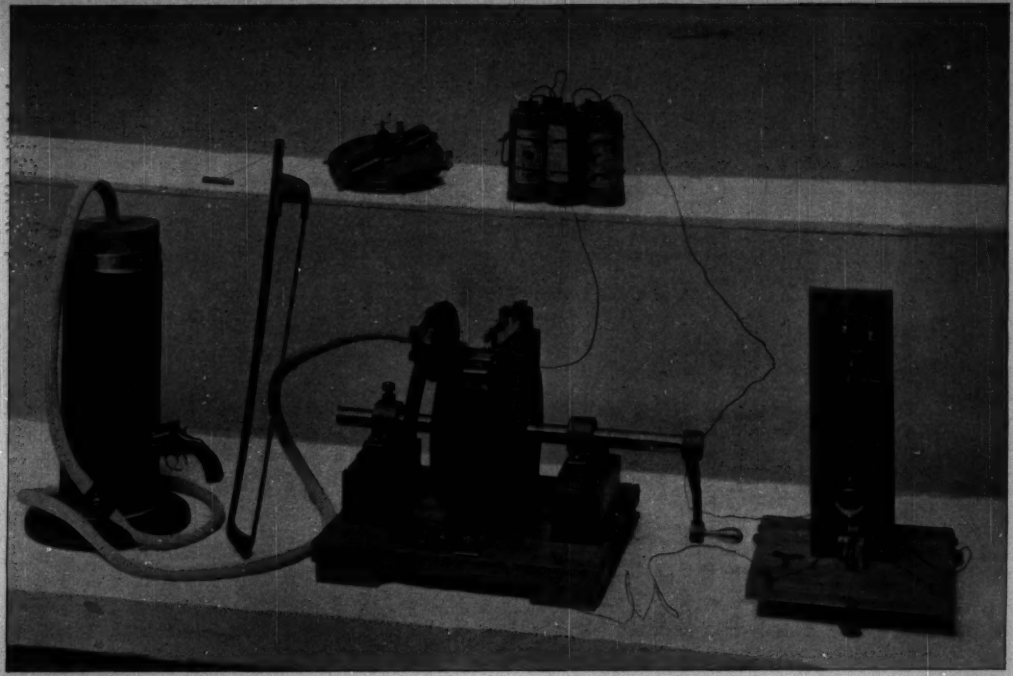


FIG. 9.—Chronograph used in Philadelphia for locating obstructions in pneumatic tubes.

for a drum, mounted upon a horizontal shaft with a crank for rotation and a screw to give longitudinal motion (see *Fig. 9*). Time was measured by the beats of a clock-pendulum, recorded on the chronograph drum by a stylus which moved under the pull of an electro-magnet at each beat of the pendulum. The pendulum was arranged to close an electric circuit in the usual manner by swinging through a globule of mercury. In addition to the clock, a tuning-fork was used to measure time by the number of waves traced on the smoked surface of the drum. For the measurement of small fractions of a second the tuning-fork is more accurate and convenient than a clock, but when the period extends over several seconds the work of counting thousands of small waves becomes very laborious.

I selected a fork tuned to 512 vibrations per second, which enabled me to measure to $\frac{1}{1000}$ of a second with a very small error. In fact, with a little care it was possible to measure to $\frac{1}{5000}$ of a second.

The fork was arranged in a horizontal position, having a horse-hair cemented to one prong, which traced a sinuous line on the drum as the latter was turned. The sound of the pistol discharge was recorded by a stylus attached to the end of an aluminum arm that rested against a rubber diaphragm. A chamber in the rear of the diaphragm was connected to the end of the pneumatic tube by a piece of rubber hose which conveyed the sound waves from the tube to the chronograph. A cock was placed in the middle of the hose and partially closed before the pistol was discharged to prevent too great distention of the diaphragm by the direct impact of the sound-waves. The cock was opened by an attendant after each discharge and before the echo returned, in order that the feeble sound-waves of the echo might not fail to be recorded.

The muzzle of the pistol was inserted into the tube through a small hole in the side, the end of the tube being closed by a funnel to which the rubber hose was connected.

When the apparatus was properly adjusted a measurement was taken in the following manner: The clock was started, the tuning-fork set in vibration by striking with a

mallet or by bowing, and the drum rotated by hand; then the pistol was discharged and the cock in the rubber hose opened. A few moments only were required to count the waves of the tuning-fork and from them compute the time.

The experiments were usually repeated several times to eliminate errors. Five experiments gave the following results:

1	2·791 seconds.
2	2·794 "
3	2·793 "
4	2·793 "
5	2·794 "
Mean	2·793 "

A thermometer was placed in the ground beside the pipe and the temperature found to be 39°. It was assumed that this was the temperature of the air in the tube. The velocity of sound at 32° was assumed to be 1,093 feet per second, and the increase of velocity for each degree of temperature to be 1·12 feet; this gives at 39° the velocity of 1,101 feet per second.

In 2·793 seconds the sound would travel 3,075 feet, which locates the carrier at 1,537 feet from the instrument. This indicated that the carrier was lodged 100 feet east of Seventh Street, and workmen were ordered to excavate at that point. Before reaching the tube, air was heard escaping from the break, and the carrier was found almost exactly where it had been located by the instrument.

It is impossible to say what the limits of the method are so far as distance is concerned, but experiments of Regnault show that the report of a pistol is no longer heard at a distance of

1,159	metres	in a tube	0·018	m.	in diameter.	
3,810	"	"	"	0·300	"	"
9,540	"	"	"	1·100	"	"

But the same sound-waves will vibrate a sensitive diaphragm at distances of 4,156, 11,430, and 19,851 metres respectively.

AN INSTRUCTIVE MECHANICAL FAILURE.

By Wilfred Lewis,
Member of the Institute.

The discovery of broad general principles is constantly removing from the field of research the hallucinations that formerly engrossed the activities of many hands and minds, and nothing illustrates more clearly the value of technical training than the check which it imposes upon the pursuit of mechanical follies. An example of this may be noted in the lives wasted on the problem of perpetual motion that might have been saved for useful work by an earlier exposition of the conservation of energy. That a few are still engaged in the hopeless task is clearly due to the imperfect dissemination of this great principle; but since the time of Redheffer, the number of these misguided enthusiasts has steadily diminished.

The craze for perpetual motion probably reached its height in 1812, when, as described by Dr. Henry Morton, in this *Journal* for April, 1896, Redheffer applied to the Legislature of Pennsylvania for a grant of funds to carry on and perfect his great invention. Instead of acceding to this modest request, the more prudent course was adopted of appointing an investigating committee, which was graciously allowed to view the wonder of the age at a respectful distance, through a glass case, but closer inspection was not invited. Nevertheless, one glance was sufficient for the keen observation of young Coleman Sellers,* as the result of which a duplicate model was soon made and exhibited with very depressing effect upon the pretensions of Redheffer, whereupon he retired to private life.

There was no refuge then for an unmasked deceiver behind the bars of a fantastic terminology known only to himself. Doubtless, people liked to be humbugged then as they do now; but no genius had ever conceived the possibility of success in a series of occult scenic effects

* Afterwards the father of our esteemed contemporary, Dr. Coleman Sellers.

purporting to illustrate a confused mummery of terms. This triumph was reserved for a later period, when satiated reason seemed to crave diversion. It is not my intention, however, to reckon with the philosophy of the Keeley motor as expounded by its alleged inventor, nor to deal with anything beyond the pale of common sense.

But, although perpetual motion has been relegated to the bottomless pit of folly by all minds capable of grasping the truth which it violates, there are other truths equally well established as laws of nature, against which the folly of would-be inventors is still beating. It is not surprising that in 1812, while the philosophy of energy was in process of evolution and before the great doctrine of its conservation had been clearly established, intense interest should have been awakened in the reputed discovery of perpetual motion. There was then some hope of success and the promise of fame and fortune to the triumphant inventor. But, at the close of this century of scientific progress, it is amazing to witness an assault upon principles formulated long before the conservation of energy, and clearly elucidated in modern text-books on natural philosophy.

Inertia is an inherent property of matter, and Newton's first law of motion, which is really a law of inertia, asserts that a body at rest remains at rest, and a body in motion continues in motion and in a straight line, unless it is deflected by some controlling force.

Newton's laws also assert the relations between force, mass and acceleration, and define force in terms of the acceleration produced upon a given mass in a given time. Physical forces are thus made comparable to the force of gravity, and the measure of force is expressed in acceleration or change of velocity. The actual velocity has nothing to do with it except as an index to the rate of change in deflected or curvilinear motion, and, in every case, the change of velocity in any given direction is the true measure of the force acting in that direction.

The laws of gravity and inertia have for centuries been known to hold the planets in their orbits, and the observed effect of these laws on the motion of matter in space has

served to detect the existence of unseen matter and point to its actual discovery, thus demonstrating the universality of natural law and its perfect precision of action in the boundless depths of space. Here the problems are grand and complex, while the data for their solution are often incomplete and uncertain, requiring the exercise of rare judgment and great ability; but in dealing with terrestrial bodies, where motion is necessarily more limited and restrained, the effect of inertia is felt directly in the restraining material, and the data for its determination are so definite and clear that no room is left for doubt or speculation of any kind. Yet on the 9th of March, 1897, we find the U. S. Patent Office actually granting patents for an alleged improvement in balancing locomotive driving-wheels on the pretension that the translation of the wheel along the rail has an important bearing, hitherto overlooked, upon the inertia of the revolving parts. Such action totally ignores the well-known fact that the revolving parts never give any trouble in balancing, and present no difficulty whatever to be overcome, and naïvely assumes the existence of an imaginary fault for the purpose of having something to correct, while the real difficulty of balancing the reciprocating and revolving parts together seems to be unheeded or unknown.

It would hardly be worth while to give an idea of this kind more than passing notice, had it not been so persistently entertained and developed, and did it not appear to be gaining credence to a remarkable extent.

The amount of time, money and enthusiasm spent in this direction can be appreciated only after an examination of the apparatus designed to sustain the contention raised, and a review of the arguments and diagrams offered in its support.

All of this is so ingenious, so plausibly presented and throws such interesting and unexpected side lights upon a subject not commonly studied, that it is hoped its exposition may compensate in some measure for the complete failure of the original purpose to improve the balance of locomotive driving-wheels.

The promoter of this laudable scheme was unfortunately misguided in his perception and interpretation of facts, but so confident was he of the success of his labors that he applied, not for a grant of funds from the Legislature, like the over-reaching Redheffer, but for a report from an investigating committee of the Franklin Institute.

It has been the privilege of the writer to serve on this committee, and, with the generous approval of the applicant, who desires the truth to be known, hoping that others may benefit by his experience, the story of this failure in balancing may now be told.

The alleged improvement in balancing a locomotive driving-wheel is shown and described in three U. S. patents

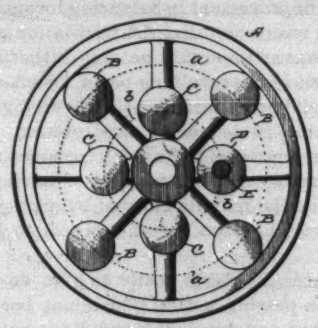


FIG. 1.

granted to Philip Z. Davis, March 9, 1897, and numbered consecutively 578,597–8–9. In the first-mentioned patent a number of weights are disposed, as shown in *Fig. 1*, four of which, including the crank pin, are in the crank circle 90° apart, while four more are in an outer circle 90° apart, and on radial lines 45° from the inner set. The weights, *C*, in the crank circle, are described as being each equal to the weight of the boss *D* and the pin *E*, while the equal weights *B*, in the outer circle, are said to be varied in weight with the ratios between the diameters of the crank circle, the balancing circle and the rolling circle, but in what manner does not appear.

In this arrangement there is but one weight opposed to the crank pin, all the other weights being made to balance each other.

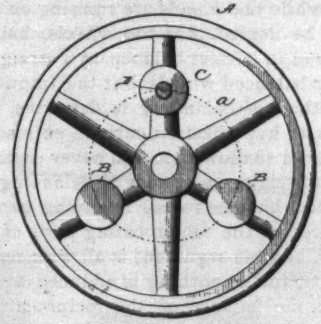


FIG. 2.

In the second patent, No. 578,598, there are two weights opposed to the crank pin, as shown in *Fig. 2*, 120° apart, and this arrangement is put forward as the most practical form of the invention.

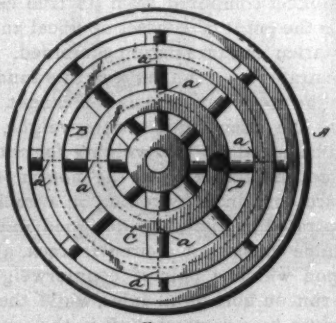


FIG. 3.

In the third patent, No. 578,599, there are, as shown in *Fig. 3*, two balancing rings, one in the crank circle and one outside, and apparently there is nothing directly opposed as a counterweight to the crank pin.

In all cases the wheels are assumed to be in running balance on their centers, and to the peculiar arrangements of counterweights is ascribed the virtue of maintaining this balance while the wheels are running on a track.

It cannot be denied that the wheels, balanced as described, will run in perfect balance on a straight track just like any other balanced wheels; but the imputation is that the usual method of balancing is defective, and adopting this fiction as an hypothesis, a curious philosophy is developed to explain a shadow that was never cast.

The inventor claims a system of balancing by which he obtains a perfect balance for all revolving parts, and an improved balance for the reciprocating parts of a locomotive driving-wheel, but his argument is all with reference to the revolving parts, and as nothing is adduced to show any improvement in the balance of the reciprocating parts, our attention will be confined to the revolving parts only. He also claims that, by using two counterweights disposed as shown in *Fig. 2*, he has overcome the difficulty in balancing locomotive drivers, and his philosophy asserts that any weight attached to a locomotive driving-wheel must have its force and effect computed from its true center of rotation, which is the point of contact of wheel and rail for the motion of rotation and translation combined.

To demonstrate in a practical way this fundamental contention that the motion of translation cannot be neglected in computing the effect of a counterweight, and to show that a wheel balanced by two weights for rotation around its center is not in balance when the motion of rotation and translation are combined by rolling on a track, the testing machine illustrated in *Fig. 4* was designed and built.

This machine consists of a circular track, about 3 feet in diameter, upon which a pair of counterweighted discs is mounted to run on horizontal axles, while the axles themselves are driven by a vertical shaft in the center of the circular track. This track is mounted on three weighing levers connected at the center to another lever, which in turn is connected to the elastic finger of a recording pencil. The vertical shaft, which drives the pair of discs, carries a large

paper drum, upon which the recording pencil can be allowed to act. The axles which carry the two discs are hinged near the center, leaving the discs perfectly free to press upon the circular track, and any variation in this pressure is shown by the movement of the recording pencil.

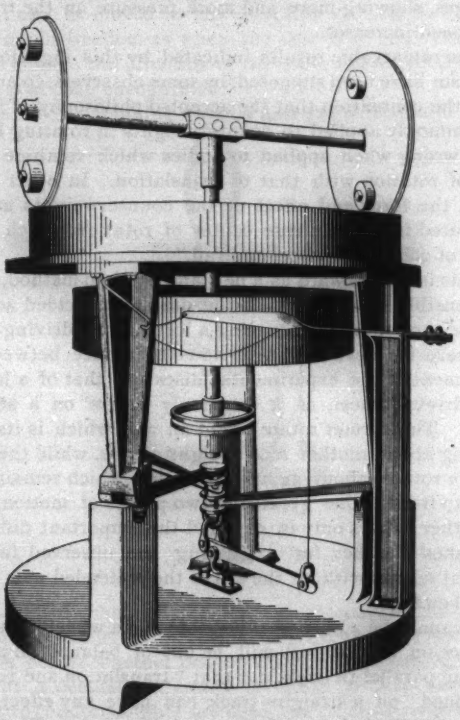


FIG. 4.

When the discs are counterweighted, as shown in *Fig. 4*, and driven at a moderate speed, the recording pencil will be set in vibration, making two complete movements for every

rotation of the disc, and, as the speed increases, the amplitude of the vibrations becomes rapidly greater. On the other hand, when the discs are counterweighted at three points, as shown in *Fig.* 2, there is no vibration of the recording pencil at any speed, but the position of the pencil changes, showing more and more pressure on the track as the speed increases.

The remarkable results indicated by this ingenious mechanism have been supposed, by some observers, to substantiate the contention that the accepted philosophy of inertia, as commonly applied to counterweights in rotating bodies, is all wrong when applied to bodies which combine a motion of rotation with that of translation. In other words, "that the force and effect of the counterweights must be computed from their true center of rotation, which is the point of contact of wheel and rail."

This is put forward as a new and original method, differing sensibly in its results and leading to a decided advance in the perfection of balancing a locomotive driving-wheel.

There is, however, an obvious difference between the movement of the experimental discs and that of a locomotive driving-wheel, as it commonly occurs on a straight track. The former rotate about an axis which is itself revolving about another axis at right angles, while the latter simply rotates about an axis in motion which remains parallel to itself. One gyrates in two planes of motion, while the other moves only in one, and this important difference furnishes the key for explaining the observed facts as natural results without the aid of the pretended new theory of balancing.

It cannot be admitted as possible that a wheel in running balance on a fixed axis will be out of balance on an axis moving parallel to itself, nor that "translation and rotation combined" on a straight track can have any effect whatever upon the balance of the revolving parts. The effects observed in the experimental apparatus are demonstrably due to gyroscopic action, and to show this in a practical way we are indebted to Mr. Hugo Bilgram for the instrument illustrated in *Fig.* 5.

It is simply a disc mounted upon an axis in a forked handle, to be spun with a cord like a top, and held in the hand. Two or three counterweights may be attached to the disc, giving, in either case, a perfect running balance.

Now, while the disc is spinning, it is found that the instrument can be moved in any direction parallel to itself, with as much freedom as when the disc is at rest; but attempt to change the direction of the axis, and a decided resistance is at once encountered.

If the disc is spinning rapidly and the direction of the

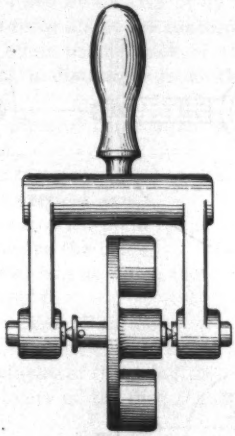


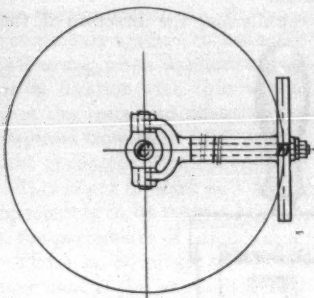
FIG. 5.

axis is suddenly changed, the instrument twists in the hand even when a strong grip is taken to prevent it. This phenomenon occurs whether two or three counterweights are used, but a decided difference in effect is also noticed. When two counterweights are used, the twisting referred to is accompanied by a series of impulses depending upon the speed of rotation, but when three are used the twist is steady and without pulsations.

This experiment is interesting and instructive, not because it exposes the futility of the elaborate testing ma-

chine to establish the fundamental contention in this new philosophy, but because it suggests the possibility that out of its failure and by its means a new and important principle of motion may accidentally have come to light. It is not surprising that the gyroscopic effect of three counterweights should be steadier than that of two, but it is at first surprising that three weights should run as steadily as four

FIG. 6.



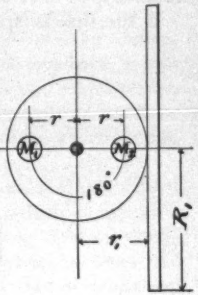


FIG. 7.

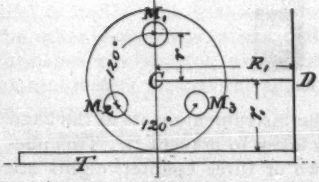


FIG. 8.

or six in two planes of motion; and a rigid analysis of the problem discloses the curious fact, which may be stated as a principle, that in gyroscopic effect three weights, disposed as shown in *Fig. 2*, 120° apart, are equivalent to a ring of the same radius and weight. This may or may not be a new discovery, but it leads to such a clear understanding of the

gyroscope, and explains so fully the observed effects in the testing machine experiments, that it is thought advisable to give the analysis in detail, after which the fallacy in the argument "from point of contact with rail" will be considered.

Given the disc D, *Figs.* 6, 7 and 8, radius r, mounted on a horizontal axis and driven on the circular track T, radius R, by a vertical shaft C, normal to the plane of the track and passing through its center, the disc being free to press upon the track, but restrained by its axis, or by a counterweight, against centrifugal force about the center C.

(1) To find the effect on the track of two equal masses, M_1 and M_2, *Fig.* 7 at a distance r from the axis and 180° apart.

(2) To find the effect of three equal masses, M_1, M_2 and M_3, *Fig.* 8, 120° apart.

Let v_1 = velocity in feet per second of the center of the disc D about the vertical axis C.

v = velocity of any other point in the same direction at a distance x above the track.

R_1 = radius $C\,D$ in feet at which the center of the disc D revolves about C.

r_1 = radius of the disc D in feet.

r = radius of the masses M_1, M_2 and M_3 to be considered.

ω = angular velocity of the axis $C\,D$.

β = angular velocity of the disc D about its axis $C\,D$ = $\omega \dfrac{R_1}{r_1} = \dfrac{v_1}{r_1}$

a_1 = acceleration normal to the plane of the disc D due to the velocity v_1.

a = acceleration normal to the plane of the disc D due to the velocity v.

From the conditions of the problem it is evident that the velocity v, of any point in the disc D at a distance x above the track T, may be expressed by the equation

$$v = \frac{x\,v_1}{r_1} \qquad (1)$$

The center of the disc D moves about C with the velocity $v_1 = \omega R_1$ and its normal acceleration is given in the well-known expression for circular motion,

$$a_1 = \omega^2 R_1 = \omega v_1 \qquad (2)$$

Here a_1, ω and v_1 are taken in a plane normal to the vertical axis C, and since ω is constant for all points in the disc D, the normal acceleration a for any point in the disc must depend upon its velocity v and be expressed by the general equation

$$a = \omega v = \omega v_1 \frac{x}{r_1} = a_1 \frac{x}{r_1} \qquad (3)$$

The force F developed by a mass M under the acceleration a is $F = M a$, but since the balanced masses are all assumed to be equal, they may be more conveniently treated as unit masses, for which we have simply $F = a$.

At the center of the disc D the normal force F_0 for a unit of mass at that point becomes

$$F_0 = a_1 = \omega v_1 \qquad (4)$$

and for any other point in the disc at the distance x above the track,

$$F = \frac{x}{r_1} F_0 \qquad (5)$$

In the case shown by *Fig.* 7, two equal masses M_1 and M_2 are assumed at the distance r from the center of the disc D and 180° apart.

For M_1 we have $x = r_1 + r$ and $F_1 = \left(1 + \frac{r}{r_1}\right) F_0$

For M_2 we have $x = r_1 - r$ and $F_2 = \left(1 - \frac{r}{r_1}\right) F_0$

The moment K_1, of the force F_1 at the distance r above the driving trunnions C is

$$K_1 = r F_1 = r \left(1 + \frac{r}{r_1}\right) F_0$$

and the opposing moment of the force F_2 is

$$K_2 = -r F_2 = -r \left(1 - \frac{r}{r_1}\right) F_0$$

The algebraical sum of these moments, or the resultant moment K, is therefore

$$K = K_1 + K_2 = \frac{2 r^2}{r_1} F_0 = 2 r^2 \omega \beta \qquad (6)$$

Now, when the masses M_1 and M_2 turn through 90° and stand for an instant at the same height r_1 above the track T, it is evident that the resultant moment K is zero, and that as the disc D runs on its circular track, K must vary by the amount $2 r^2 \omega \beta$ twice for each rotation of the disc. Dividing the moment $2 r^2 \omega \beta$ by the arm R_1 through which it acts, the variation in the pressure on the track may be expressed by the equation

$$\Delta P = \frac{2 r^2 \omega \beta}{R_1} \qquad (7)$$

Since the center of gravity of the masses M_1 and M_2 is always in the center of the disc D, it is evident that the sum of the forces $F_1 + F_2 = 2 F_0$ is constant, and deducting F_0 from F_1 and F_2 respectively, we have the components $F_1 - F_0$ and $F_2 - F_0$ causing moments about C, and the central force $2 F_0$ along the radius $C D$.

$$F_1 - F_0 = \frac{r}{r_1} F_0 \text{ and } F_2 - F_0 = -\frac{r}{r_1} F_0$$

the first of which acts at the distance r, causing the moment

$$\frac{r^2}{r_1} F_0$$

while the second acts at the distance $-r$, causing the same moment, the sum of which is

$$2 \frac{r^2}{r_1} F_0 = 2 r^2 \omega \beta$$

as given in equation (6).

For any arrangement of equal balanced masses, the sum of the moments K can therefore be expressed as the sum of the components $y^2 \omega \beta$, in which y is the vertical distance of

each point of mass above or below the plane of motion for the axis *C D*.

In other words, we have

$$K = \Sigma\, y^2\, \omega\, \beta \tag{8}$$

by which the analysis for three or more masses can be easily followed.

In *Fig. 3* there are three unit masses, M_1, M_2 and M_3, at the distance r from the center and 120° apart. M_1 acts at the distance r above the center, M_2 and M_3 each act at the distance $r\ sin.\ 30°$ below the center, and the sum of the moments K is, by equation (8),

$$K = (y_1^2 + y_2^2 + y_3^2)\, \omega\, \beta \text{ or}$$

$$K = \left(r^2 + \frac{r^2}{4} + \frac{r^2}{4}\right) \omega\, \beta = 1{\cdot}5\, r^2\, \omega\, \beta \tag{9}$$

Now, if we let these masses keep the same relative positions and be shifted through an angle θ, we have

$y_1 = r\ cos.\ \theta$, $y_2 = r\ sin.\ (30° - \theta)$ and $y_3 = r\ sin.\ (30° + \theta)$

$y_1^2 = r^2\ cos.^2\theta$, $y_2^2 = r^2\ sin.^2(30° - \theta)$ and $y_3^2 = r^2\ sin.^2(30° + \theta)$

$sin.^2(30° - \theta) = \frac{1}{4}\ cos.^2\theta - \sqrt{{\cdot}75}\ sin.\ \theta\ cos.\ \theta + {\cdot}75\ sin.^2\theta$

$sin.^2(30° + \theta) = \frac{1}{4}\ cos.^2\theta + \sqrt{{\cdot}75}\ sin.\ \theta\ cos.\ \theta + {\cdot}75\ sin.^2\theta$

Therefore $y_1^2 + y_2^2 + y_3^2 = 1{\cdot}5\ r^2\ (sin.^2\theta + cos.^2\theta)\ \omega\ \beta = 1{\cdot}5\ r^2\ \omega\ \beta$, as shown by equation (9) for the original position.

With three unit masses at the same distance from the center and 120° apart, there is, therefore, no change in the resultant moment of the centrifugal forces, and for the constant pressure on the track due to these forces, we have

$$P = \frac{1{\cdot}5\ r^2\ \omega\ \beta}{R_1} \tag{10}$$

Similarly it may be shown that the total energy E stored in the masses M_1, M_2 and M_3 is constant, and for this the value is expressed by the equation

$$E = 3\ \omega^2\ R_1 + 3\ \beta^2\ r + 1{\cdot}5\ \omega^2\ r \tag{11}$$

The sum of the centrifugal forces $F = F_1 + F_2 + F_3$ is

also constant and equal to 3 F_0, and it must therefore be concluded that three equal masses 120° apart, as shown in *Figs.* 2 and 8, will run as steadily as a homogeneous ring without variation in pressure on the track or periodic impulses of any kind.

In the above analysis, the disc *D* has been treated as a very thin sheet of metal, and the masses M_1, M_2 and M_3 as points of weight in that plane, whereas the disc must have sensible thickness and the counterweights must have volume.

From the results obtained, however, the analysis is easily extended to a disc of any thickness and to weights of any size as cylinders therein.

Since three points of mass, as shown, are equivalent to a homogeneous ring of their combined mass at the same radius, it can be shown from equation (9) that a ring of unit mass at the radius r will exert the moment

$$K_r = \cdot 5\, r^2\, \omega\, \beta \qquad (12)$$

and from this equation it is evident that the moment K_r is independent of the position of the assumed ring along the axis *C D*. Equation (12) therefore applies to a thin cylinder of any length, and from this the moment K_d for a solid disc of unit mass will be found to be

$$K_d = \cdot 25\, r^2\, \omega\, \beta \qquad (13)$$

For three cylindrical counterweights, each of unit mass, 120° apart, having a radius r_0 and acting at the radius r from the axis *C D*, we have

$$K_3 = 1 \cdot 5\, r^2\, \omega\, \beta + \cdot 75\, r_0^2\, \omega\, \beta \qquad (14)$$

It is thus possible to determine for any given disc, weighted as shown in *Figs.* 2 and 8, the increase in track pressure due to its speed and the curvature of the track. Obviously, if the track is straight, ω becomes zero, and there is no increase of pressure.

Referring again to *Fig.* 7, it should be observed that, although the sum of the centifugal forces $F_1 + F_2$ is constant and equal to 2 F_0, the total energy of motion *E*, like the track pressure, is variable. For two unit masses at the

radius r, this variation in energy ΔE may be expressed by the equation

$$\Delta E = 2 r^2 \omega^2 \qquad (15)$$

and this will set up plus and minus impulses in the plane of the axis $C D$, parallel to the track.

A disc with two balanced masses, 180° apart, is therefore characterized while running on a curved track, by impulses upon and along the track, the latter tending to fluctuate the angular velocities ω and β, while the former simply varies the pressure on the rail.

For convenience in estimating this variation in rail pressure, equation (7) may be written in the form

$$\Delta P = \frac{2 r^2 \omega \beta}{G} \qquad (16)$$

where G, the gauge of the track, becomes the arm of the couple.

For example, suppose a driving-wheel 6 feet in diameter has a mass of 10 concentrated at the crank pin 1 foot radius, and an equal mass at the same radius directly opposite, and let this wheel be running on a curve of 1,000 feet radius at the rate of 90 feet a second, or a little over a mile a minute, the gauge of the track G being 5 feet, to find the variation in rail pressure.

Here $\omega = \frac{90}{1000} = \cdot 09$, and $\beta = \frac{90}{3} = 30$. Substituting these values in equation (18), we have

$$\Delta P = \frac{2 \times 10 \times \cdot 09 \times 30}{5} = 8 \cdot 4 \text{ lbs.}$$

a very insignificant amount for quite an extreme case; but this refers to one driver only, while the other driver on the same axle must have the same masses disposed at right angles to the first.

There are, consequently, four equal masses 90° apart to be considered, and referring to the general equation for the moment of centrifugal forces, $K = \Sigma y^2 \omega \beta$, we have, when M_1 and M_3 are in a vertical line and M_2 and M_4 in a horizontal

line, at the radius r, $y_1 = r$, $y_2 = o$, $y_3 = r$ and $y_4 = o$. The sum of the moments $y^2 \omega \beta$ is, therefore,

$$K = 2r^2 \omega \beta \qquad (17)$$

Now, letting all these masses turn through a small angle θ, we have

$$y_1 = r \cos. \theta, y_2 = r \sin. \theta, y_3 = r \cos. \theta, y_4 = r \sin. \theta$$

and the sum of the moments becomes

$$K = 2r^2 (\sin.^2 \theta + \cos.^2 \theta) \omega \beta = 2r^2 \omega \beta$$

as before. If the crank pins are balanced by equal masses directly opposite, it thus appears that no fluctuation in track pressure can occur from this cause even when the wheels are running on a curved track at high velocity. It is also quite apparent, by the method just employed, that this conclusion applies as well to a pair of drivers counterweighted in the usual manner by weights near the rim instead of in the crank circle, and it cannot be doubted that the usual method of balancing a pair of locomotive driving-wheels is as perfect in effect as any of the methods claimed to be an improvement in the patents referred to.

The recognized difficulty in counterbalancing driving-wheels, on account of the counterweight being in a different plane of motion from that of the crank pin, and also on account of the inertia of the reciprocating parts, remains unnoticed, and need not be discussed. We now come to the argument "from point of contact with rail," in support of which the gyroscope has been so futilely employed.

It is claimed that the force and effect of a counterweight in a locomotive driving-wheel must be computed from its true center of rotation, the point of contact of wheel and rail for the motion of rotation and translation combined.

Since inertia forces in a given direction are invariably accompanied by a change of velocity in that direction, it is impossible to imagine how the accelerations and retardations due to rotation can be at all affected by rectilinear translation in any direction.

The addition of a constant to a variable never affects its differential, and it is clearly the difference in velocity

divided by the difference in time that measures accelerations. This, in fact, is the definition of the term; but to show more conclusively the fallacy in the argument presented, and the utter lack of any foundation whatever upon which the alleged improvement in balancing can be based, we will consider the actual path traced by a point in the driving-wheel with reference to the track.

The path traced by any point between the center and the circumference of a rolling circle is known as a prolate cycloid. A point in the crank circle *G G*, *Fig. 9*, traces the curve *C G K*, *Fig. 10*, and a point in the outer circle *H H*, *Fig. 9*, traces the curve *B I H*, *Fig. 10*, also shown to a larger scale as *B*, *B'*, *B''*, etc., *Fig. 11*. These curves are both con-

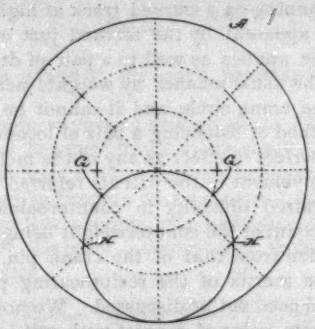


FIG. 9.

cave and convex to the track, and their points of inflection, *G G* and *H H*, where the curvature changes, have been particularly specified in the first-mentioned patent as points where there is no normal force, the argument being that while the curve is concave, the centrifugal force in the moving weight is away from the track; and while convex, the centrifugal force has a downward component upon the track. This would, undoubtedly, be true for a body moving in a prolate cycloid at a uniform rate, but it is certainly not true for the variable rate at which the body actually does move, because the inertia of the body in the line of its travel is wholly neglected.

No matter whether the center of the rolling disc or its point of contact with the rail be considered as fixed, it is perfectly clear that any point in the disc attains its maximum vertical velocity as it passes the center line, and that, consequently, on either assumption, the neutral point in the vertical forces must be on that line.

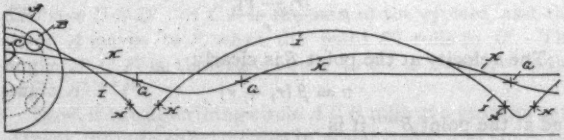


FIG. 10.

Now, if the disc is rotating about its center O, *Fig. 11*, at the angular velocity β, we would certainly find the vertical force exerted by a unit of mass at the point B, radius r by the equation

$$F = \beta^2 r \tag{18}$$

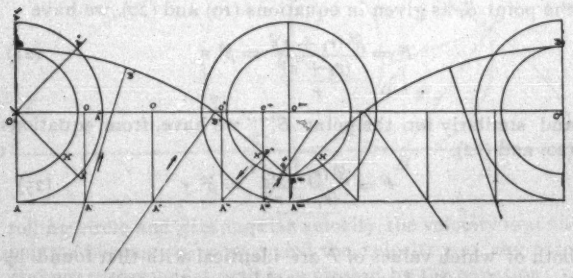


FIG. 11.

and for the point B'''' we would have the same force in the opposite direction, but it is claimed that these forces should be computed from "the true center of rotation, the point of contact of wheel and rail."

Very well; let us look at the problem from the same point of view and accept without question the demonstration given in "Proctor's Geometry of Cycloids," that the radius

of curvature of the prolate cycloid at the point B is expressed by the equation

$$\rho = \frac{(r_1 + r)^2}{r} \tag{19}$$

and for the point B''''' by the equation

$$\rho = \frac{(r_1 - r)^2}{r} \tag{20}$$

The velocity at the point B is clearly

$$v = \beta (r_1 + r) \tag{21}$$

and at the point B''''' it is

$$v = \beta (r_1 - r) \tag{22}$$

A unit of mass moving with the velocity v at the radius ρ develops the centrifugal force expressed by the equation

$$F = \frac{v^2}{\rho} \tag{23}$$

and substituting in this equation the values of ρ and v for the point B, as given in equations (19) and (20), we have

$$F = \frac{\beta^2 (r_1 + r)^2}{\frac{(r_1 + r)^2}{r}} = \beta^2 r \tag{24}$$

and similarly for the point B''''' we have, from equations (20) and (22),

$$F = \frac{\beta^2 (r_1 - r)^2}{\frac{(r_1 - r)^2}{r}} = \beta^2 r \tag{25}$$

both of which values of F are identical with that found by the usual method and expressed in equation (18).

It thus appears that the centrifugal force at the points B and B''''' of the prolate cycloid, *Fig. 10*, is the same, whether estimated from the center of the circle or from the point of contact of wheel and rail, and, since the translation of the wheel along the rail means nothing more than a constant added to the horizontal velocity at any point as determined for a fixed center, it is perfectly clear that translation along the rail can not affect accelerations in any direction.

No further demonstration is required, but it may be of interest to add a more general solution on geometric lines for the force of inertia developed at any point in a cycloidal path.

Referring to *Fig. 12*, let P be any point in the cycloid $D\,A\,D'$ formed by the point A, in the rolling circle $A\,C\,B$ on the base $D\,B\,D'$. $A\,C\,B$ is the axis of the cycloid, and the point A moves to P, when the point B'' rolls to B'. The angle $A'\,C'\,P$ is, therefore, equal to $B\,C\,B''$, and twice the angle $A'\,B'\,P$.

Now, if the describing circle $A\,C\,B$ rolls at a uniform rate it turns through equal angles in equal times, and since the angle $A'\,B'\,P = \theta$ is always half of the angle $B\,C\,B''$, the line $B'\,P$, joining the contact point B' with the describing point P, must also be moving with a uniform angular velocity. Using our original notation, where r_1 = radius of the

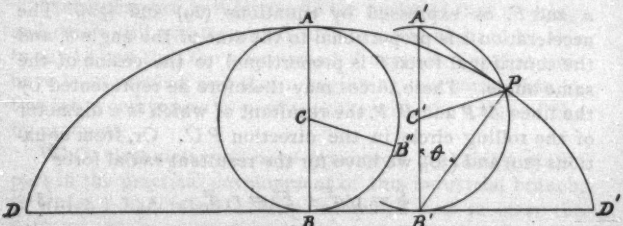


FIG. 12.

rolling circle and β its angular velocity, the velocity v_1 at the point A becomes $v_1 = 2r_1\,\beta$, and the velocity v at any point P along the cycloidal path is expressed by the equation

$$v = 2r_1\,\beta\,cos.\,\theta \qquad (26)$$

Having found v, the acceleration a can be determined from the general equation

$$a = \frac{d\,v}{d\,t} \qquad (27)$$

Differentiating, equation (26) gives

$d\,v = 2r_1\,\beta\,(-\,sin.\,\theta)\,d\,\theta$, in which we have $d\,\theta = \frac{d\,\beta}{2}$ and substituting this value,

$$d\,v = -\,r_1\,\beta\,d\,\beta\,sin.\,\theta \qquad (28)$$

Obviously $$d\,t = \frac{d\,\beta}{\beta}$$

and we have $$a = \frac{d\,v}{d\,t} = -\,r_1\,\beta^2\,sin.\,\theta \qquad (29)$$

in which the minus sign indicates retardation.

To find the centrifugal force at the point P acting in the direction $B'\,P$, we have the velocity v by equation (26), and the radius of curvature at P being known to be $2\,B_1\,P = 4\,r_1\,cos.\,\theta$, the centrifugal force for a unit of mass is given by substituting these values of v and R in the general formula

$$F = \frac{v^2}{R}, \text{ whence } F = \frac{(2\,r_1\,\beta\,cos.\,\theta)^2}{4\,r_1\,cos.\,\theta} = r_1\,\beta^2\,cos.\,\theta \qquad (30)$$

We now have a mass at P under the impulse of two forces, a and F, as expressed by equations (29) and (30). The acceleration a is proportional to the sine of the angle θ, and the centrifugal force F is proportional to the cosine of the same angle. These forces may therefore be represented by the lines $A'\,P$ and $B'\,P$, the resultant of which is a diameter of the rolling circle in the direction $P\,C'$. Or, from equations (29) and (30), we have for the resultant radial force

$$S = \sqrt{a^2 + F^2} = r_1\,\beta^2 \qquad (31)$$

which will be recognized as the general equation for centrifugal force in a unit of mass moving about a fixed center at the radius r_1 with the angular velocity β.

The patents referred to in what has preceded are thus shown to be in contempt of well-established principles, and therefore worthless.

They are as clearly untenable as the idea of perpetual motion, and yet they are the outgrowth of honest enterprise and toil, diligently continued for many years. Technical training in the right direction might have saved the mental energy and material substance so lavishly thrown away. The moral, "A little learning is a dangerous thing," remains as a warning, and as a fruitful result, perhaps some interest may be awakened in a mysterious toy of considerable scientific importance.

CHEMICAL SECTION.

Stated Meeting, Tuesday, November 16, 1897.

AMMONIA AND ITS SOURCES.

By Dr. Bruno Terne,
Member of the Institute.

Since I had the pleasure of addressing the Chemical Section on this subject, six years have rolled by. Members who were present at the October meeting, 1891, will remember the spirited debate which took place over the probabilities of the ammonia production in connection with the cokeries of the United States.

I take pleasure in referring to the report of that meeting, and it is a still greater satisfaction to me to-night to be able to say to you that the views which I expressed at that time have been verified, and that a beginning has been made by two large companies to produce coke with the gains of the by-products.

While circumstances have prevented my taking active part in the practical development of this industrial branch, in which I had taken a deep interest, I had to leave the field to others more favorably connected. I cannot but feel proud that the views which I expressed six years ago have since been indorsed by reality, and that a new industry has been established in our country.

In my paper I dwelt mainly on the Otto system, of which the patent rights for the United States were purchased by a syndicate about three years ago, with headquarters first in Cleveland, O., and now in Pittsburg, Pa.

The first ovens were constructed in the coke department of the Cambria Iron Company, Johnstown, Pa., and very satisfactory results have been reported. I am not quite sure of the number of Otto ovens in operation in this country; the report in *Mineral Industry* for 1895 puts the number at 60, but I feel sure that this number has now been more

than doubled. I know of 120 Otto ovens being erected in McKeesport, Pa., alone.

In Germany, 2,237 Otto ovens were in operation in 1895, and 480 more of the most improved pattern were built in 1896, in the Ruhr District alone; no more Beehive ovens are being built there, they being replaced with the Otto ovens as they wear out. While in Germany the Otto system is outnumbering all others; Belgium, France and England have also adopted other systems, of which I only name Simon-Carvès, Huessner and Semet-Solvay.

The Semet-Solvay system has taken a firm foothold in the United States; there being in operation to-day 25 ovens at Syracuse, N. Y.; 25 at Sharon, Pa., and 50 at Dunbar, Pa.; in course of erection, 120 ovens at Birmingham, Ala.; 120 at Wheeling, W. Va., and 10 ovens at Halifax, N. S. In reality, the Solvay Company has been the pioneer of this industry in the United States. The first ovens of this kind were, to my best of recollection, built in 1892, and after a year's trial their number has increased to the present figures.

When Prof. George Lunge, in his excellent paper on this subject, published in *Mineral Industry* for 1896, stated that he was informed at the Chicago Exposition (1893) that no coke ovens existed at that time, the report was practically correct, because there were none in the coal regions, and the trials at Syracuse, N. Y., were not generally known. It is worth repeating what this most eminent authority on technical chemistry says:

"The only rational method of coke manufacture is that which utilizes to their full extent the products of the destructive distillation of the coal, instead of wasting them by burning at the mouth of the distilling apparatus, as is done in the antiquated Beehive oven.

"A few words will dispose of the alleged drawbacks of the modern coke ovens, which utilize the heat of their gases.

"The principal objection, tenaciously upheld until quite recently by most of the leading English and American iron-masters, has been that the coke made in new ovens is inferior to the Beehive oven coke, both in respect to crushing strength and fuel value.

V. 18

"Some of these gentlemen roundly maintained that such coke was simply unfit for use in the blast furnace; others were at least positive that much more of it than of Beehive coke was needed for making pig iron. These views might, at any time, have been refuted by a visit to some Belgian or Rhenish-Prussian iron works; but most of the gentlemen concerned would have scorned to admit that they could learn anything about iron-making from continental people, and would have deemed such visits wholly superfluous.

"Another objection has been made on the difference of cost of erection.

"There are about 45,000 beehive ovens in existence in the United States; their abolition means, of course, the annihilation of a very large capital.

"There is something in the argument, taken from this fact, against the introduction of the new style, but not very much.

"It is simply a matter of calculation whether the interest on the capital required for building new ovens is greater or less than the profits corresponding to the increased yield of coke, and that represented by the value of the by-products.

"The readers of the *Mineral Industry* know well enough that the coke-makers of the United States, until a year ago, have been behind even their British colleagues in this matter.

"When visiting the Chicago Exposition in 1893, I saw, of course, the pretty model of the Connellsville coke ovens in the Mining Building, with the gas flames representing the spectacle offered by the oven mouth on the large scale, and, in the presence of Mr. H. Clay Frick himself, I was asked if I did not admire that exhibit, but I was bold enough to say in that gentleman's presence that I could not bestow any admiration upon the demonstration of an utterly irrational and antiquated method of conducting a technical process.

"I was then informed that not a single coke oven of the novel type was then in existence in the United States, and the same objections were repeated to me which had been

made and refuted over and over again in Europe. To this, of course, I could only shrug my shoulders."

Since then the ban has been broken, and I am satisfied that the step of progress from now on will be a rapid one; the material gain of the new process over the old one will brush away, in a comparatively short time, all prejudice.

Let us pause for a moment, and study the comparative costs between the old and new processes, on the enclosed table, which is taken from *Mineral Industry*, 1895.

The 45,000 beehive ovens have a capacity of 78,750 tons per day, at a cost of $28,350 per day; while the same quantity in the improved Otto oven would cost $10,237 per day, or in the Semet-Solvay system, $4,725.

I can hardly think that, in the face of the fact that the Otto system has gained such universal adoption in Germany, where the strictest economy in all branches of industry is the rule, that it could be so much higher in cost than the Semet-Solvay system; but we have the authority of the General Manager of the Cambria Iron Works, who has stated, as his conclusion respecting the comparative working of different retort ovens, that the Semet-Solvay oven is 30 per cent. quicker in operation than any of its competitors.

Mr. R. M. Atwater, the Secretary of the Semet-Solvay Company, of Syracuse, N. Y., asserts that a single Semet-Solvay oven will produce 2,000 tons of coke from Pocohontas coal, or 1,600 tons from Connellsville coal in one year.

No oven in Europe or America has reported results within 30 per cent. of this record.

To all appearances, at the present time, it seems that the Semet-Solvay oven has taken the lead in economy of operating, by reducing the time of coking.

The 350 Semet-Solvay ovens now in operation are equal to the production of 1,400 tons of coke per day, only $\frac{1}{56}$ part of the capacity of the existing Beehive ovens, but they, in conjunction with the Otto ovens in operation, are the nucleus of a new era in the chemical industry of our land.

We need only to recall how long a time it took to supersede sulphur in the manufacture of sulphuric acid, but how quickly, after the first step had been taken, the pyrites took possession of this industry as a main source.

COMPARATIVE TABLE OF COKE-OVEN COSTS—THEIR OUTPUT AND COST PER TON OF COKE.

Items.	Kind of Oven.									
	Not Recovering By-Products.				Recovering By-Products.					
	Beehive.	Pelgian.	Bernard.	Coppée.	Otto-Hoffman.	Simon-Carvés.	Huessner.	Semet-Solvay.	Festner-Hoffman.	Siebel.
Cost per oven	$300	$900	$1,000	$1,000	$4,160	$2,400	$2,750	$3,000	$3,000	$2,500
Output of coke per day per oven, net tons	1·75	2·40	2·25	2·20	3·34	2·2	2·9	4·0	2·94	3·10
Yield of coke	65 p.c.	68 p.c.	75 p.c.	72 p.c.	75 p.c.	75 p.c.	75 p.c.	75 p.c.	75 p.c.	75 p.c.
Number of ovens required to produce 100 tons of coke per day	58	42	44	46	30	46	35	25	34	33
Cost of plant to produce 100 tons of coke per day	$17,400	$37,800	$44,000	$46,000	$124,800	$110,400	$96,250	$75,000	$102,000	$82,500
Repairs and depreciation per ton of coke	0·047	0·102	0·119	0·124	0·337	0·298	0·264	0·203	0·275	0·223
Labor on coke and by-products per ton of coke	0·320	0·270	0·250	0·270	0·390	0·390	0·390	0·390	0·390	0·390
Total cost per ton of coke	0·367	0·372	0·369	0·394	0·727	0·688	0·654	0·593	0·665	0·613
Value of by-products per ton of coke	—	—	—	—	0·530	0·530	0·530	0·530	0·530	0·530
Net cost per ton of coke	0·367	0·372	0·369	0·394	0·197	0·124	0·124	0·063	0·135	0·083

From the yields of coke from the different ovens shown in above table, it will appear that the beehive requires 1·54 tons of coal to make a ton of coke, while the ovens saving the by-products require 1·33 tons. The value of disposable gas is not included in the figures given, as this will vary greatly according to local conditions, but under any circumstances it should not be less than 20 cents per ton of coke. Adding this value to that of the other by-products, it is safe to say that the cost of coke in the by-product ovens does not exceed the cost of the coal from which it is made.—*Mineral Industry*, Vol. IV, p. 242.

The Pittsburg coal has given an average of from 18 to 22 pounds of ammonia per ton of coal, reckoning it as sulphate.

Taking an average of 20 pounds of sulphate of ammonia per ton of coal, we are still suffering the daily loss of over 2,000 tons sulphate of ammonia by the use of the existing beehive ovens.

Should all the ammonia ever be gained it would not be too much, as the demand for it is constantly growing larger.

A most important step for another source of ammonia has been made by Dr. Ludwig Mond, and brought first to notice in 1889, in his presidential address to the Society of Chemical Industry.

Dr. Mond found that the amount of nitrogen contained in different fuels which he experimented on varied between 1·2 and 1·6 per cent.

When he introduced, together with the superheated air required to burn the fuel in the producer, 2½ tons of steam to every ton of fuel consumed, he found that over 70 per cent. of the total nitrogen in the fuel could be recovered in the form of sulphate of ammonia per ton of fuel from the producer gases. This amounted in practice to nearly 100 pounds of sulphate of ammonia per ton of fuel.

It would take up too much time to go into details of the construction and handling of this gas producer.

Dr. Mond has overcome all adverse criticism of his method by erecting an experimental steel plant in 1895, at the Winnington Works, England, of Messrs. Brunner, Mond & Co. I refer all who are especially interested in this subject to the *Journal of the Iron and Steel Institute*, No. 1, for 1896, in which Mr. John H. Darby published in detail all information desirable.

The Solvay Process Company, of Syracuse, N. Y., has erected a plant of eight Mond producers at its works, replacing the use of coal in the steam plant and elsewhere.

The Semet-Solvay Company controls the Mond process in the United States, and all who are interested in the application of this process will be best served by corresponding with the Secretary of this company Mr. R. M. Atwater.

Fuel gas affords the practical solution of the question of

the smoke nuisance; no factory should be allowed to create such by the use of soft coal. Fuel gas should be delivered to every household of our metropolitan cities, at a price competing favorably with coal.

The production of fuel gas with the gain of ammonia has been demonstrated to be a practical process, which allows the prospect of a return of 25 per cent. on the capital invested.

In the production of ammonia from other sources, I mention the proposition of Sternberg to utilize the sugar-house waste for such purpose by ignition of a mixture of molasses with alkali-aluminate. This process has been patented in the United States under the name of F. O. Matthieson. There are numerous other proposals made, but none have yet brought practical results.

The problem of utilizing the nitrogen of the air as a source for ammonia is still unsolved.

Lord Rayleigh had lately made a study of the oxidation of free nitrogen under the influence of the electrical spark. Siemens & Halske claim that when air, or oxygen and nitrogen, are mixed with ammonia, and subjected to the influence of an electrical discharge, a profitable yield of ammonium-nitrate may be obtained.

It seems, from the results obtained by Lord Rayleigh and Siemens and Halske, that the presence of an alkali to combine with the oxides at the instant of formation is necessary.

Russell and Frank, following the suggestion of Winkler, heated together at red heat, in an open crucible, a mixture of calcium-carbide and magnesium powder, and find that practically all the magnesium is converted to nitride; also, under similar conditions, aluminum, zinc and iron will take up nitrogen.

Mehner, and likewise Willson, exposed such elements as boron, silicon, magnesium, and titanium, which are capable of combining with nitrogen at high temperature, to the heat of the electric furnace, in presence of carbon and nitrogen.

Frank obtained aluminum-nitride by heating the finely-divided metal with powdered calcium-carbide, and declares

that when the metal is heated with dry slaked lime, the nitride may be obtained in large quantities.

Practically, all the nitrides yield ammonia when mixed with water in the cold; the aluminum compound decomposes very slowly. On this ground Frank claims manurial value for it.

The production of nitrides in the electric furnace, by the methods of Mehner and of Willson, may become profitable sources of ammonia.

It will obviously depend on the cost to determine which process will be able to compete with the sources of ammonia which are based on the organic nitrogen compounds provided abundantly by nature.

In close connection with the production of ammonia comes the production of cyanides. This highly interesting and likewise important field lies outside of my subject tonight. I refer you to the review of Prof. Wm. McMurtrie, in the November number of the *Journal of the American Chemical Society*, from which I also quoted the researches to utilize the nitrogen of the air by means of the electrical furnace.

About a year ago we had the pleasure of hearing Prof. H. W. Wiley, of Washington, D. C., tell us of his experiments with bacteria culture to produce nitrogen in the soil.

The firm of Meister, Lucius & Bruning, of Hoechst a-Main, produces cultures of bacteria commercially; the cultures are enclosed in bottles, each containing a sufficient quantity to inoculate half an acre of ground.

These nitrogen-fixing bacteria, when introduced to soils free from them and unsuited to the cultivation of leguminous plants, produce in the roots of such plants nodules, or tubercles, in which fixation of free nitrogen and its conversion into assimilable forms are effected. It is claimed that sterile soil becomes fruitful, and will produce good leguminous crops when inoculated with the bacteria. This new form of agriculture is not over the stage of first experiment; the success of the new enterprise to furnish fertilizer in homœpathic doses remains to be established.

A comparatively new source for ammonia, at present ex-

clusively for the benefit of the farmer, has been created by the utilization of garbage, producing a fertilizer.

At the meeting of the Section, June 20, 1893, I read a paper on the utilization of garbage. At that time the question of disposal of this waste material was hotly debated in our city. The fight was waged over the respective merits of Cremation *vs.* Utilization.

Convinced of the great wrong of destroying this valuable material, I came before your body, and, through the *Journal* of the Institute, before the public at large, called attention to the folly of destroying a material which, if properly handled, is a valuable source for the production of a fertilizer and also of grease.

This paper was well received by the public press, as well as the contemporaries of the *Journal*.

The companies which disposed of the garbage at that time by incineration adopted the method the following year. The same gentlemen who took up the utilization of garbage as a business enterprise were successful in 1896 in securing the contracts for the cities of New York and Brooklyn, and late in 1897 for the city of Boston.

Since September 1, 1896, I have been connected with these companies as chemical manager, and, as such, may be permitted to dwell somewhat more in detail on this new industry, which promises to be an important factor, not only in the fertilizer trade, but also in the grease market of the United States.

The processes of utilization may, in the main, be classified as three distinct methods:

(1) The extraction of the greases by hydrocarbons or the naphtha process.

(2) The acid process. Dissolving the crude garbage in sulphuric acid, and after the liberation of the greases, transforming the whole mass at once into a super-phosphate.

(3) The steam-rendering process, commonly known as the Arnold process.

The ideal process, from a theoretical point of view, is certainly the extraction process by naphtha. On account of the prevailing high prices of naphtha, and the unavoid-

able losses of the same, this process has proved to be unprofitable. The first plan of this kind, in Providence, R. I., operating under the Simonin process, is out of existence. The same process in New Orleans, La., has proved to be a financial failure. What system shall take its place has not been decided upon, but a plant operating in Cincinnati, O., is the only one working under these patents.

The cities of Buffalo, Detroit, Milwaukee and St. Louis are working under the Merz naphtha system, but their methods, however, have been so modified that in reality they constitute a steam-rendering system.

The Arnold system is successfully carried on by the American Product Company, of Philadelphia, and the New York Sanitary Utilization Company. Pittsburg is operating under the method of the American Reduction Company—the acid process. Bridgeport, Conn., has a small plant working under the Holtzhous patents, a system apparently well-arranged, but too expensive for practical purposes.

The Philadelphia plant of the American Product Company is situated at the foot of Morris Street and the Schuylkill River. Col. Waring, of New York, in his report on the utilization of waste materials, speaks of the plant as follows:

"Mechanical appliances of the most modern design render manual labor almost unnecessary, and the process is rapid, simple and inexpensive."

The most extensive plant of all is that at the works of the New York Company, situated at Barren Island, in New York Bay. The daily accumulation of garbage of the two cities is varying from 1,000 to 1,500 tons per day, depending upon the season of the year. In the city of New York the gathering is done by the street-cleaning department; in Brooklyn, by contract. In both places the material is loaded on scows, which are towed down to the island. The material is taken by a movable conveyer to the top of the digester room, where it is distributed to the digesters by means of swivel spouts. A digester can be filled with a 9-ton charge in five minutes. The original plant was built to care for the city of New York alone; but since the Brooklyn contracts

have been added the company has duplicated its plant, and will be prepared to handle the increase of material during the summer season with ease.

The great difficulty of handling such vast amounts of material is to apply the most economical methods; the starting of such an enormous work was certainly not without serious trouble. Well planned as the construction of the works has been, it was unavoidable that practical defects should have shown themselves; but step by step the management has made improvements, powerful condensers have been added to care for the escaping gases from the digesters and from the dryers. The liquors from the digesters, which were heretofore allowed to go to waste, are taken care of by a 150,000-gallon triple effect evaporator, built by the Sugar Apparatus Company, of Philadelphia, under the Lillie patents. I have finished, a few weeks ago, the trial test of this apparatus, and after adjusting the same to the peculiar qualities of our liquors, I dare say that we have, in the Lillie apparatus, the very best device to care for our liquors by the utilization of waste steam.

Utilizing the garbage of the two cities, we will add 2,400,000 pounds of ammonia in form of fertilizer, available to the soil, annually to the gain of ammonia.

Adding to the output of our plants the output of other plants, it will be readily acknowledged that by the utilization of city garbage, an enormous quantity of ammonia has been put in circulation, and a benefit to agriculture has been created which has already made itself felt. The fear has been repeatedly expressed that if all the large communities will care for this waste material, the over-production will make the enterprise unprofitable. There is hardly any reason to accept this theory as well founded. In the first place, agriculture demands from year to year more artificial nutrition to the soil; second, the scarcity of stable manure which has been created by the introduction of electrical tramways, doing away with tens of thousands of horses all over the country, makes necessary the replacing of this commodity by some other suitable material, and no manure is better adapted by its physical qualities than the garbage fertilizer to answer this purpose.

Mining and Metallurgical Section.

Stated Meeting, May 11, 1898.

THE MICROSTRUCTURE OF BEARING METALS.

BY GUILLIAM H. CLAMER,
Chemist to the Ajax Metal Company, Philadelphia,
Member of the Institute.

The science of microscopic metallography is at present attracting widespread attention, and great developments have of late resulted from this mode of testing. Microscopic examination is fast becoming a factor in testing metals. In the study of iron and steel much work has been done and much information obtained; but the microscopic examination of alloys is a comparatively new piece of research. Chemical analysis can show only the composition of an alloy; but to show the true structure, or manner in which the component parts are alloyed, is left for the microscope. The physical properties of a sound piece of steel depend exclusively upon its chemical composition and upon its structure, and just so with all other alloys; not only should the component parts thereof be known, but also the manner in which these metals are alloyed, as is shown by their structure. We may take, for instance, bearing metals. In these alloys two all-important points requisite to a good bearing alloy, namely, anti-friction and wearing qualities, are greatly dependent upon structure.

It is, of course, first necessary to have the composition correct to meet certain requirements, such as load, speed, etc., and then to have the component parts alloyed in such a manner that the product shall be as fine-grained and homogeneous as possible. The failure of many bearings to give satisfactory service is more often the result of improper mixing than of a poor composition.

It is an undisputed fact that certain combinations of metals are better than others, but it frequently happens that

an alloy of good composition is far inferior to another of poor composition, simply on account of improper manipulation; a good composition in the hands of unskilled foundrymen often yielding a granular and uneven mixture of very inferior quality, while a good metal can be made of inferior scrap by another.

How the wearing qualities are dependent upon structure will be made evident when we consider the definition of wear—"the tearing off of small particles from the worn bodies." Therefore, a bearing metal which is finer in granular structure will wear the slower because of the tearing off of smaller particles.

If a metal is not homogeneous, the anti-frictional qualities will suffer greatly, because of the difference in the hardness and density of the metal in all its parts. The particles of such an alloy form hard spots within the metal, which produce friction.

The homogeneity is greatly dependent upon the treatment the alloy has undergone, and a perfectly even structure can only be obtained by careful and proper treatment.

In view of these considerations, I was led to make a study of the structure as well as the composition of the various bearing metals on the market in this country, and more particularly those which are used in railroad service.

The question as to what is the best metal on which to run our rolling stock is one which is becoming more important every day. We are running our trains on faster schedule; we are increasing the size and weight of locomotives and cars to acquire greater speed, greater carrying capacity and greater comfort.

Only a comparatively few years ago railroad men would have laughed at the idea of attaining the train weights and speeds of to-day. They would have advanced a hundred difficulties in the way of achieving such wonderful results, and chief among these would have been cited the difficulty of obtaining a bearing metal which would meet these requirements. In former times, when speed was not attained and comfort but little considered, a "hot box" was of little consequence; but now the numerous trains are required to

dash along with marvellous regularity, reaching their destination after a run of hundreds of miles on the very minute they are scheduled to arrive. Under these conditions even the slightest delay often leads to the most disastrous consequences. Many accidents are on record which can be traced to a hot box.

Apart from the safety and successful movement of trains which can be accomplished only by the use of well-fitted, well-lubricated bearings, composed of a properly made anti-friction alloy, the question of cost is also an important factor—not only first cost, but also the expense which is directly dependent upon the wearing qualities of the alloy and its successful use as scrap. A metal to be successfully used as scrap must have the quality of not deteriorating in remelting. The importance of these considerations is at once obvious to a well-regulated railroad, which considers the great loss occasioned by wear, and the necessity of converting their scrap again into a first-class journal brass.

The alloys now in use for this purpose may be divided into five classes:

(1) White metal alloys.
(2) Miscellaneous alloys.
(3) Copper and tin alloys.
(4) Phosphor-bronze.
(5) Copper, tin and lead alloys.

Cast iron has been tried as a journal metal on railroads, and in fact was used for some years, but I think that it has now been entirely abandoned for the composition metals. Roller bearings have also been experimented with, but, so far as I am aware, have failed to give satisfaction.

The preparation of these alloys for microscopic examination is, of course, of first importance. They must be carefully polished and then etched with a suitable reagent. For copper alloys I prefer to use method of Guillemin, *i. e.*, to attack the specimen electrolytically by exposing it for a few minutes in a bath of very dilute sulphuric acid when connected with a simple Daniel cell, and, in making a comparative study of metals of similar composition, all the conditions must be the same. The method I use is to make a

platinum dish, containing the weak acid solution, the positive pole, and then immerse the specimens to be compared in the solution in contact with the dish, and pass a current through them all at the same time.

The white metal alloys belong to the first class. They are first in anti-frictional qualities, but do not wear well, and furthermore have not sufficient strength to support the great weight of locomotives and cars without distortion or crushing. The practice, therefore, is to use these metals inside of a stronger shell of composition metal.

In car bearings these soft alloys are simply used as a lining, which is not more than $\frac{1}{16}$ to $\frac{1}{8}$ of an inch in thickness. The object of this lining is to give the bearings a good seat without having to be bored out accurately to fit the diameter of each individual axle. The diameters of the axles vary according to the wear they have had, and to fit hard-metal bearings it would be necessary to bore each one to fit each particular axle, and moreover the axles are always more or less rough. The soft white metals easily conform to any such irregularities in the surface of the axle.

This soft composition soon wears away, but by the time this has taken place the bearing has a good seat on the axle, thus doing away with the necessity of fitting each separate journal. The boxes are all bored out to the same diameters and lined with a specified thickness of soft metal. In this way the bearings are all fitted with the minimum expense and confusion. The principal alloy used is one containing antimony and lead; this is sold on the market under the name of "hard lead." It usually contains from 15 to 25 per cent. of antimony, which makes the alloy coarsely crystalline and brittle. It is inexpensive, but gives little wear. Although antimony is a more expensive metal than lead, the "hard lead," or antimonial lead, sells at a lower price than pure lead. The microstructure shows these coarse crystals (*Fig. 1*). With the increase of antimony the crystals are brought into closer contact, indicating the approach to the chemical alloy. Tin greatly improves this alloy. It gives it greater toughness, and makes an alloy which will stand a much greater pressure without distortion, a valuable feature for a babbitt metal.

This is the composition of nearly all the cheap babbitt metals on the market. A good babbitt metal should have as fine a grain as possible in connection with the greatest toughness and hardness obtainable. Tin has the property of greatly reducing the granular texture of antimonial lead. Bismuth in small quantity is added to the lead, antimony and tin alloy by some manufacturers. It is claimed to give greater fluidity and less distortion under pressure. The composition of such an alloy is:

Lead	80·00
Tin	4·75
Antimony	15·00
Bismuth	·25

The question of obtaining a fine-grained structure depends greatly on the method of manufacture, temperature of pouring playing an important part, but generally the size of the crystals increase with the increase of antimony, as does hardness; but by proper manipulation a finely crystalline metal can be obtained in an alloy of the following composition, which has a high percentage of antimony, thus making it a valuable babbitt metal:

Lead	70·00
Antimony	20·00
Tin	10·00

The first white metal successfully used as a bearing metal was invented by Isaac Babbitt. It contained tin, antimony and copper. This metal is used for lining purposes, but can be cast into solid bearings which do not carry too great a load. All white metals used for bearing purposes are now sold under the name of babbitt metal, and when used as a lining the bearing is said to be "babbitted." But to distinguish this metal from the cheaper lead alloys it is sold under the name of "Genuine Babbitt." This alloy is harder than the lead alloys, much tougher, and is finely crystalline and wears well. It is much more expensive, owing to the content of tin. The composition is as follows:

Tin	80·00
Copper	10·00
Antimony	10·00

Another alloy very successfully used is one composed of:

Tin	68·00
Zinc	31·50
Copper	1·00
Lead	·50

It is very tough and bends many times without breaking, due to the peculiar interlocking of the crystals (*Fig. 2*). It has, however, the bad feature of pouring sluggishly. I have no knowledge of the wearing qualities of this metal.

I will next consider the miscellaneous alloys. Under this head may be included any alloy, it matters not what the composition, so long as it produces a reasonably good casting. It includes all alloys having over 60 per cent. of copper and the remainder made up indiscriminately of zinc, tin, lead, antimony and any other metals which happen to be in the scrap pile.

Such compositions as these are used on freight cars, and, indeed, by some roads in passenger service, their only aim being to get a cheap composition. No attention is paid to wearing or other qualities, and the running expense is not taken into account; it is only first cost. If a bearing gets hot or wears out, it is removed and thrown into the scrap pile, to be again remelted. Foundrymen receiving this scrap term it all "red brass," and without any knowledge of the composition, again convert it into journal bearings.

The scrap pile always contains more or less zinc, and indeed anything from yellow brass up is considered good enough for a cheap bearing metal,

Fig. 3 shows the structure of yellow brass of:

Copper	66⅔ parts
Zinc	33⅓ "

It is beautifully crystalline and the size of the crystals varies greatly with the method of treatment. Zinc has the property of giving greater solidity to alloys of copper, tin and lead, 1 to 2 per cent. being sufficient for this purpose, and when more than this is used in connection with other scrap the effect is more or less injurious. If the scrap metal coming from the railroads was first melted and run into pigs

and analyzed, uniform results could be obtained by building up the scrap with new metal to the desired composition; but the present low price of such material would not warrant this extra expense; and, indeed, I have known of such bearings to be cast, bored out and lead-lined for 7½ cents per pound. But even so, with proper care, a fairly good metal can be made from such scrap.

Fig. 4 shows a bearing metal made of scrap which has been carefully treated; it contains a high percentage of lead, but shows no liquation of the lead as would be expected in an alloy of this nature.

Fig. 5 shows a copper and tin alloy, containing a little lead, in which manganese has been used as a deoxidizer.

The alloy of copper and tin some years past was considered the standard bearing metal on railroads, but is now little used. These metals alloy to form a very hard and crystalline alloy, *Fig. 6*, the usual proportion being that of cannon bronze—7 parts of copper to 1 part of tin. Although this alloy is much harder than the standard metals of to-day, yet it is found to wear much more rapidly and produce more friction. Dr. Dudley, chemist to the Pennsylvania Railroad, some years ago gave the results of a long series of experiments before the Franklin Institute, in which he compared the copper and tin alloy with standard phosphor-bronze, which contains lead. He found that the copper and tin alloy was much more liable to heat under the same state of lubrication than the standard phosphor-bronze, and second, that the rate of wear with the copper and tin alloy was nearly 50 per cent. greater than that of the standard phosphor-bronze. And still, in spite of these facts, some railroads still go on in the old way specifying copper and tin, a more expensive alloy than the phosphor-bronze, or the copper, tin and lead composition.

These experiments led directly to the use of standard phosphor-bronze bearing metal on the Pennsylvania Railroad, and indirectly to its use on other large roads. Thus, by practical experimentation and experience, railroad men to-day recognize but two alloys as standard: (1) Copper, tin and lead alloy, containing phosphorus, known as phosphor-

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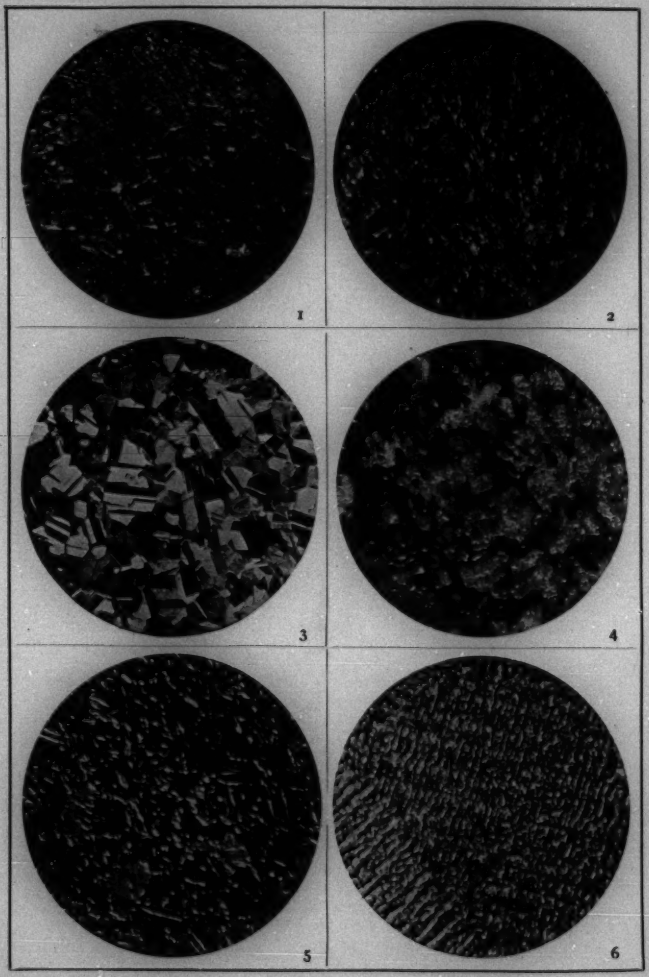

FIG. 1.—Antimonial lead.
FIG. 2.—Tin and zinc with little copper and lead.
FIG. 3.—Copper and zinc.
FIG. 4.—Copper, zinc, tin, lead, iron.
FIG. 5.—Copper and zinc with little lead (manganese used as deoxidizer).
FIG. 6.—Copper and tin.

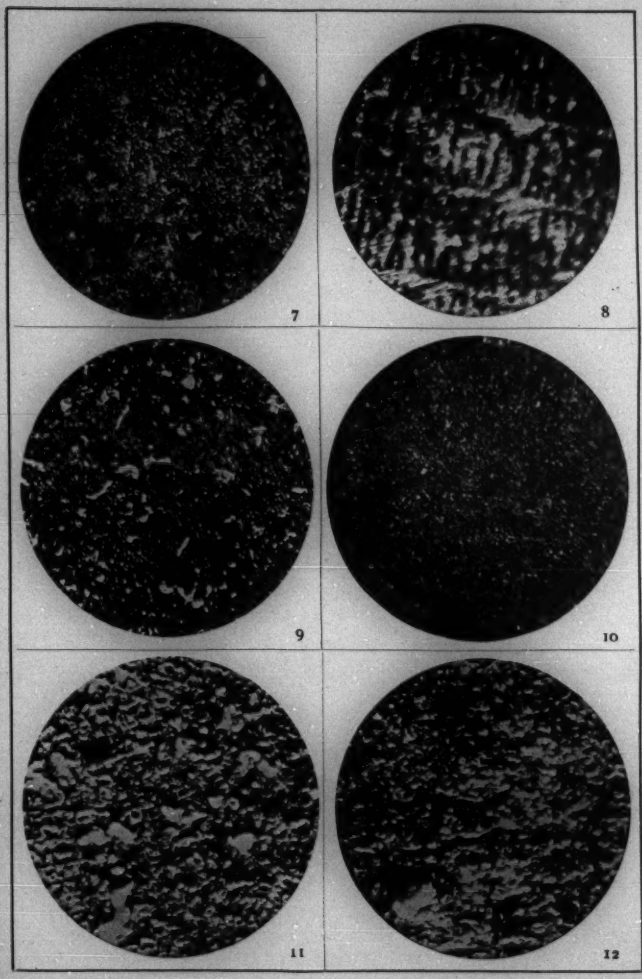

FIG. 7.—Copper, tin, lead and phosphorus (1st melting).

FIG. 8.—Copper, tin, lead and phosphorus (after repeated meltings).

FIG. 9.—Copper, tin and lead (1st melting).

FIG. 10.—Copper, tin and lead (after repeated meltings).

FIG. 11.—Copper, tin and lead, showing liquation of lead.

FIG. 12.—Copper, tin and lead, showing liquation of lead.

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bronze. (2) Copper, tin and lead. I do not say that either of these alloys is the best that can be devised, but up to the present time, and with our present knowledge, they are the best compositions for car and locomotive journal bearings. As far as wearing is concerned, I do not think the phosphorus introduces any advantage, and, as Dr. Dudley says, he has no evidence to show that the phosphorus has any other use except to produce sound castings.

I had occasion very recently to find, by a practical test, that the alloy of copper, tin and lead gave better results, so far as anti-frictional qualities are concerned, than the alloy containing phosphorus. That the bearings without phosphorus showed a much less tendency to heat than the phosphor-bronze was clearly demonstrated. The test was made by placing the phosphor-bronze on one side of the axle and the simple alloy on the other. The tests were strictly comparative in every way, and the number of hot boxes of the phosphor-bronze metal greatly exceeded the simple alloy. And it has been found, by practical experience, that remelted phosphor-bronze is much more liable to heat than the newly-made metal.

In order to discover why the remelted scrap phosphor-bronze should be inferior to the newly-made material, I determined to make some experiments in a practical way. The fact that the phosphor-bronze scrap is far inferior to new metal is well known, and I believe the general impression has been that the inferiority was due to the burning out of the phosphorus, as it is for this reason that the specifications of standard phosphor-bronze call for a high percentage of phosphorus, in order to make provision for loss in remelting, and with the idea that the remelted scrap will still retain sufficient phosphorus not to deteriorate its qualities. By my experiments I find this to be an entirely mistaken idea, because, in the first place, phosphorus only burns off in very small proportions, when once thoroughly contained in the alloy; and secondly, that the inferiority of the metal is directly due to the high percentage of phosphorus, for the reason that it combines with the tin and copper to form hard crystalline phosphides, which are, to a

great extent, dissolved in the alloy when the metal is new, but separate or crystallize out in the old material.

Six hundred pounds of phosphor-bronze was made of good selected material, and every precaution used in manipulating. It was then poured into ingots and borings taken from the first, middle and last ingots, and the borings mixed and analyzed. The analysis showed:

Copper	78·72
Lead	9·89
Tin	10·58
Phosphorus	1·04

Three hundred pounds of these ingots was now weighed off and remelted, and again poured into ingots and weighed, and the loss carefully noted; the metal being melted and poured in this way ten times, and the loss noted in each heat with the following results:

	Pounds.		*Pounds.*
1st	3·5	6th	2
2d	3·0	7th	3
3d	3·0	8th	3
4th	2·5	9th	4
5th	3·5	10th	7

The total loss was 34·5 pounds, or 11·5 per cent. on ten heats, and the average loss per heat 1·5 per cent. It will also be seen how uniform was the loss on every heat; the last heat only showing considerable deviation, which I attribute to the metal being insufficiently hot to flow cleanly from the crucible.

Borings were taken from the first, middle and last ingots of the tenth heat, well mixed and analyzed. The metal now contained its constituents in the following proportions:

Copper	80·39
Tin	10·40
Lead	8·35
Phosphorus	·87

The analysis shows that very little phosphorus has gone off, despite the fact that the metal was melted and poured ten times, the lead showing the greatest loss. The following table will show the loss in weight very closely, as shown by the analysis:

	1st Heat.	*10th Heat.*	*Loss in Pounds.*
Copper	235·47	213·41	22·06
Tin	29·67	27·61	2·06
Lead	31·74	22·17	9·57
Phosphorus	3·12	2·31	·81

These results show that the phosphorus is held in bronze in the form of phosphides, which high temperature can drive out only in very small proportions. The metal under the microscope was now decidedly crystalline. These crystals are intermixed or held dissolved in the new metal, but when subjected to remelting become organized and crystallize out in the alloy, thus greatly reducing the anti-frictional and wearing qualities of the metal. The resulting metal after the tenth heat was so hard it could scarcely be touched with a file. { *Fig. 7.*—New phosphor-bronze. *Fig. 8.*—Remelted phosphor-bronze.

A copper, tin and lead alloy of the same composition was treated in the same way; the loss on this metal was 34 pounds, being within half a pound of the phosphor-bronze, and the loss on each heat was as follows:

	Pounds.		*Pounds.*
1st	7	6th	4
2d	3	7th	2
3d	1	8th	3
4th	4	9th	3
5th	4	10th	3

This metal became harder and closer-grained after the repeated meltings, but showed no signs of becoming crystalline or granular.

Fig. 9.—New copper, tin and lead alloy.

Fig. 10.—Remelted copper, tin and lead alloy, made by the Ajax Metal Company's process, which insures the homogeneous distribution of the lead.

Many alloys of copper, tin and lead are manufactured by foundrymen under the name of anti-frictional metal and are sold under various well-sounding names, which are supposed to indicate their qualities.

To one who is unacquainted with or does not consider the chemical and physical properties of lead, it appears an easy matter to make such an alloy by merely melting in a

crucible the three metals in the stipulated proportions; but when we consider the greater density, the lower melting point, and the slight affinity of lead for the copper and tin alloy, a more serious question results. I have found, by my repeated microscopic examinations of many such alloys of different makers, that lead is in no instance combined or really alloyed with the copper and tin, or perhaps only in small proportions, probably not over one per cent.; the remaining lead being held diffused through the alloy in its combined state, or with small proportion of the tin and copper, but not enough to destroy the grayish-blue color.

Such an alloy under the microscope is seen to be made up of two principal colors, the bronze-colored combined copper and tin, and the grayish-blue lead. Now, this being the case, it will be seen how difficult and also important it is to obtain an alloy which will show the same structure and percentage of lead in all its parts. The difficulty in obtaining such an alloy is this, as I have stated:

(1) The lead is not combined with copper and tin.

(2) Owing to the high specific gravity and the lower melting point of the lead, its tendency is to go to that part of the casting which has last solidified, or to distribute itself unevenly throughout the mass.

I will now show the structure of copper, tin and lead alloys of several makers; they all have about the same composition and were all cast in the same size bars, great care being taken to have the conditions as nearly alike as possible. A section was cut out of the middle of each bar for examination.

Fig. 11 shows the structure of an alloy of the following composition:

Copper	76·88
Tin	10·62
Lead	11·71

It shows that the lead has liquated, leaving an unsound metal. The dark spots are holes and the lighter particles lead. That such a segregation of the lead greatly reduces the value of a composition of this nature is very evident.

Fig. 12.—A metal of following composition:

Copper	76·66
Tin	11·68
Lead	10·83

This shows a still greater segregation of lead. In this metal the lead is very unevenly distributed, it having formed large pools through the alloy.

Of all metals, lead is by far the first in anti-friction qualities; and if to the strength of copper and tin there is added a suitable proportion of lead, thoroughly and evenly distributed throughout the mass, the bearings as they wear are constantly in contact with soft anti-friction particles of lead, which are backed by the harder particles of copper and tin. If in such an alloy the lead is not homogeneously distributed and without liquation, both the wearing and anti-frictional qualities are greatly affected.

After going through the whole subject of the composition of metals suitable for bearings, the thoroughly homogeneous alloy of the proper proportions of copper, tin and lead seems to me to be the best suited for the purpose, and this has also been demonstrated in actual service by the use of such an alloy on all the record-breaking trains of recent years, notably the New York Central & Hudson River Flyer from Albany to Buffalo, which made the run of 436½ miles in 407 minutes, with the bearings perfectly cool throughout the entire run; and on the fleetest ocean greyhounds that cross the ocean.

The alloy of copper, tin and lead, of proper composition and homogeneous structure, I think I am safe in saying, has greater anti-frictional qualities than any other composition of sufficient strength to be used as a journal brass in railroad service. This fact has been demonstrated several times by actual practical tests, and furthermore, it does not deteriorate in remelting.

As structure is of such importance in a bearing metal, I think the micro-test should be included in all specifications as equal, if not greater in importance than chemical analysis.

DISCUSSION.

MR. JAMES DE BENNEVILLE.—Mr. Clamer's paper with the microsections he has exhibited throws additional and

valuable light on the structure of alloys which recent investigation is beginning to connect so closely with the action of solvents and dissolved substances. To refer more particularly to iron carbides, the microstructure of these bearing metals and of steel can be read together in the same light only up to a certain point. In comparing the two, the structure of the eutectic is an important determination. These mixtures have been shown, by the interesting work of Mr. Charpy, to possess a laminar structure, and are described by him as of the same nature as cryohydrates, the heterogeneity of which has been thoroughly established by Offer. Granted such heterogeneity, presence or absence of structure has a most important bearing on the structure of steel and kindred iron carbides. Mr. Charpy has pointed out that in the pearlyte structure of annealed steel all the conditions of a eutectic are found. Now, if we turn to the much-discussed ·90 carbon steel quenched above Ar_3 (martensite), this is not found to be the case. Micrographists are substantially agreed that no structure can be detected in such steel. It is homogeneous. Two explanations have been put forward to explain this case: (1) that the carbon is dissolved in the iron and all compounds have disappeared, the relation of carbon to iron being analogous to that of sugar in water; and (2) that a definite compound of iron and carbon has been formed, viz.: $Fe_{24}C$. Difficulties arise in applying either of these explanations. If at high temperatures carbon is simply dissolved in iron, and is so retained on rapid cooling, thus forming a solid solution, the chemical relation known to exist between iron and carbon, and giving rise to cementite (Fe_3C) must be put aside, but it is to be noted that although carbon can be dissolved by iron, only carbide of iron can be again separated on slow cooling, unless a certain percentage of carbon is exceeded. If, however, the presence of cementite is admitted, the unusual example is presented of complete dissociation of the compound Fe_3C in somewhat concentrated solution, whereas it has been found that in the case of electrolytes the more advanced the dissociation the greater is the dilution required. For

carbon, martensite covers the range up to ·90 per cent. In quenched low carbon steel of ·20 carbon, microanalysis shows two constituents, ferrite and martensite. If martensite is a definite compound, the explanation $Fe_{24}C$ is accepted. If it is structureless in ·90 carbon quenched steel, there is surely no reason to assume structure in ·14 carbon quenched steel. To reject definite composition is to grant that martensite of ·90 carbon steel is not identical with martensite of ·14 carbon steel. If martensite varies in composition with the composition of the steel in which it is found, one distinguishing feature of a eutectic is at once lost, viz.: constancy in its physical properties; for this very constancy first gave rise to the idea that these mixtures, having constant boiling points, freezing points, etc., were definite chemical compounds. It is the definition of a eutectic.

As cast iron and vitreous silicates showed analogies in their conduct toward reagents, the writer (1894) was led to associate these "mother liquors" of iron carbides with such vitreous silicates. If martensite is regarded as analogous to such a compound, many difficulties are removed, and its varying composition, ultimate and proximate, can be understood. Can the indefinite structure of the vitreous silicates be regarded as necessarily implying a solution holding ions of calcium, magnesium, silicon and other elements? The definite ratios found to exist in the silicates, and which allows their range and the replacing value of each element to be predicted, does not uphold this view. The vitreous silicates can indeed be regarded as a solvent for certain compounds (feldspar, etc.), in the sense that water is a solvent. It does not imply anything more. Moreover, it is to be remembered that solution does not necessarily imply ionization, of which instances can be cited in the small value of μ for complex organic acids, and also when solvents other than water are used. The homogeneity of ·90 carbon steel, hardened by quenching from 1,000°—martensite—presents peculiarities not yet detected in the structure of the alloys described by Mr. Clamer and others.

THE PRESIDENT OF THE SECTION.—The phenomenon known as "segregation" of alloys, which has been alluded to

by Mr. Clamer in his interesting paper on the microstructure of bearing metals, is a remarkable one, apparently forming an exception to ordinary chemical laws.

It is an important subject for investigation by metallurgists and chemists, and if the microscope can cast new light upon the strange behavior of such alloys it will add much to the practical utility of this instrument in the laboratory.

Segregation is often used as a convenient cloak to cover faults of melting; but apart from this, it is indeed a serious trouble to the melter who aims to obtain homogeneous alloys.

The most thorough investigation of segregation with which I am familiar was made in the assay department of the mint, a good many years ago, with various alloys of the precious metals used in coinage. It was proved that when gold and copper were melted together in the proportion required for the American coin, *i. e.*, 900 parts of gold and 100 parts of copper, and the molten metal poured into ingots, after having been thoroughly rabbled with a plumbago stirrer, a homogeneous alloy resulted; test pieces cut from different ingots all assayed alike, within a minute fraction—not more than one or two ten-thousandths variation above or below the standard. When, however, an alloy of 900 parts of silver and 100 parts of copper was poured into ingots, after having been thoroughly mixed, considerable irregularity was found to exist in the distribution of silver in different ingots, and even in different parts of one ingot, and this variation was proved to be solely owing to segregation into richer and poorer alloys; furthermore, it was discovered that there was a specific alloy of silver and copper of certain proportions—I believe about 750 parts of silver and 250 parts of copper—in which segregation was almost *nil*.

In some of the silver-copper alloys the silver segregates towards the center of the mass, leaving copper in excess near the exterior portion. In other similar alloys a reverse effect was observed, and this is, of course, independent of the specific gravity of the metals.

The coinage silver laws of the United States permit a

comparatively large variation (called the "legal tolerance"), from the standard equivalent to $\frac{8}{1000}$ above or below 900 fine, on this account; but segregation may actually cause a variation in the fineness of two silver dollars struck from one ingot, or even in the metal clipped from different parts of a single dollar, sufficient to condemn the coin if judged from these assays alone; in order, therefore, to obtain an average sample of a melt of standard silver-alloy for coin, it is the universal practice in minting operations to dip out from the melting pot (containing usually 3,000 ounces of fluid metal) a small sample immediately after thorough stirring, and to quickly pour it into cold water; the alloy is thus instantly congealed into the form of shot or "granulations" and segregation does not occur under these conditions. Assays are then made of these granulations, and duplicate analyses must agree within very small limits of permissible variation.

About twenty years ago I made some few investigations with the microscope of silver-copper alloys with the view of trying to ascertain the cause of segregation, but met with little encouragement, and I am interested, therefore, to know whether Mr. Clamer has succeeded in solving this riddle through his more thorough study of the microstructure of bearing metal alloys.

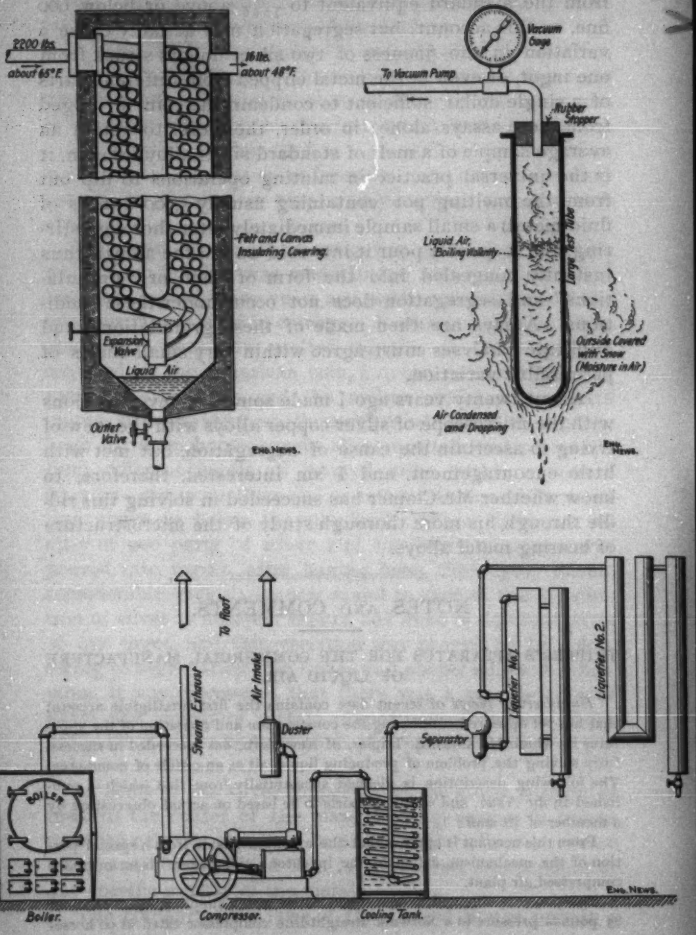
NOTES AND COMMENTS.

TRIPLER'S APPARATUS FOR THE COMMERCIAL MANUFACTURE OF LIQUID AIR.

Engineering News of recent date contains the first intelligible account that has yet appeared concerning the construction and operation of the apparatus by which Mr. Chas. E. Tripler, of New York, has succeeded in successfully solving the problem of producing liquid air as an article of commerce. The following description is gleaned substantially from that which is published in the *News*, and which purports to be based on actual observation by a member of its staff:

From this account it appears that the apparatus, aside from a special portion of the mechanism, called by the inventor a "liquefier," is an ordinary compressed air plant.

The power is obtained from a steam boiler which supplies steam at about 85 pounds pressure to a Norwalk straight-line compressor rated at 90 horse-


2200 lbs.
about 65° F.
16 lbs.
about 48° F.
Felt and Canvas Insulating Covering.
Expansion Valve
Liquid Air
Outlet Valve
Eng. News.
Vacuum Gage
To Vacuum Pump
Rubber Stopper
Liquid Air, Boiling Violently
Large Test Tube
Outside Covered with Snow (Moisture in Air)
Air Condensed and Dropping
Eng. News.
To Roof
Steam Exhaust
Air Intake
Duster
Separator
Liquefier No. 1
Liquefier No. 2.
Boiler
Eng. News.
Boiler.
Compresser.
Cooling Tank.

power when running at 150 revolutions per minute. The steam cylinder is 16 x 16 inches. There are three air cylinders arranged in tandem with the pistons all on the same rod. The low-pressure cylinder (10¼ inches in diameter) is double-acting, and raises the pressure from that of the atmosphere to between 55 and 65 pounds. The intermediate is single-acting (6⅜ inches in diameter), and compresses to between 350 and 400 pounds. The high-pressure cylinder (2¾ inches in diameter) is single-acting, and delivers the air at a pressure of from 2,000 to 2,500 pounds per square inch.

The compressor takes its air supply through a dust separator placed in the roof, thus insuring the admission of clean air. This separator is an arrangement of baffle-plates over which water is constantly trickling. From the high-pressure cylinder the air passes to a cooling tank—a spiral coil of copper pipe surrounded by a stream of running water. The purpose of this device is to carry off the heat stored in the air during its compression. The air passes on then at the temperature of the cooling water. From the cooling coil the air next passes through a "separator," or dryer, the function of which is to remove the moisture contained in it originally and that which it may have taken up in the dust separator and elsewhere.

The next piece of apparatus is what the inventor calls a "liquefier," the function of which is to transform the now cool air—which is at a pressure of about 2,200 pounds to the square inch—into liquid air at atmospheric pressure and at a temperature 312° F. below zero. In this portion of the Tripler apparatus, therefore, the actual work of liquefaction is performed. There are two of these liquefiers in use in the laboratory apparatus here described. Their operation is substantially as follows:

The comparatively cool air under high pressure enters at one end of the liquefier, where it passes through an arrangement of coils of pipes towards the other end, where there is situated an expansion valve of peculiar construction which permits a certain amount of air to escape into the surrounding casing. This expanding air flows in a direction opposite to that of the entering air, and, in flowing in and about the coils, it absorbs heat from the incoming air, greatly reducing its temperature. This accumulative chilling action of the expanding portion of the air continues to reduce the temperature of that contained in the coils more and more, until at length its "critical temperature" (placed by Dewar at 220° F. below zero) is reached and a portion of the air collects at the bottom of the liquefier in the liquid form, while the remainder flows on, expanding and continuing to exert its chilling effect on other portions of entering air. Externally, these liquefiers resemble sections of covered steam pipe, and give no intimation as to the duty they perform. The liquid air is removed from the liquefier by opening a valve in the bottom.

The laboratory apparatus above described is capab'e of producing from 3 to 4 gallons of liquid air per hour continuously.

[The *Journal* is indebted to *Engineering News* for the use of the accompanying illustrations.] W.

JAPANESE PATENT LAW.

In the treaty entered into March 11, 1897, between Japan and the United States of America, were provisions for the protection by patents in either

country of the inventions of citizens of the other. The Japanese patents are granted for any one of three terms, namely, five, ten or fifteen years, reckoned from the date of registration, these terms not being alterable after the patent has been granted. Designers of improvements on patented inventions are required to obtain a license from the patentee of the original invention before applying for a patent upon the improvement. If this license to use the original invention cannot be obtained, the Minister of State may grant the patent, fixing the compensation to be paid to the original patentee. No annuities are required, but patents shall be forfeited when the patentee, without sufficient reason, has not exploited his invention within three years of the date of his patent, or discontinues working the invention for three years at any time, or when the patentee imports and sells an article for which he has obtained a patent, or acquiesces in the selling of an article which infringes his rights. Infringers of patent rights are liable for damages to the patentee, the term of liability being three years.—*Electrical World.*

THE CARBON DIOXIDE MOTOR.

At the stated meeting of the Franklin Institute held April 20th, Mr. Wm. F. Roberts described and exhibited in operation an engine devised by him, which is actuated by carbon dioxide.

The engine exhibited was a triple cylinder machine, 2-inch bore and 2-inch stroke, double acting. It was shown in both vertical and horizontal types. In the horizontal engine the bed-plate is 24 x 14 inches; and in the vertical form 14 x 10 inches; height, 18 inches. The power is transmitted from both ends of crank-shaft.

The cylinders are fitted with positive, automatic cut-off valves, operated by a cam mechanism and cutting off at one sixty-fourth of an inch. The claim is made that the engine is capable of running at 2,000 revolutions per minute under a pressure of 1,500 pounds per square inch, and of developing under those conditions twenty-five horse-power. The total weight of this horizontal form of engine, including bed-plate, is eighty-five pounds.

The engine is supplied with gas from steel cylinders containing the carbon dioxide in the liquefied state, communication with the cylinders being established through a small copper pipe coiled in the form of a helix. In this helix the gas is heated until the desired pressure is obtained. A very large return is claimed. W.

THE ALUMINUM INDUSTRY.

From London *Engineering* we learn that the present output of aluminum in the world is a little less than 10 tons a day, of which about one-fifth is produced in the United States. In Great Britain, the British Aluminum Company has its works, at the Falls of Foyers, in full operation, using about 3,500 horse-power for the production of calcium carbide and aluminum, and making about 6,000 pounds of the latter a day. This company is making preparations for a very much larger output. In France the Société Electro-Metallurgique Française, at Le Praz, makes 3,600 pounds a day with 3,000 horse-power by the Heroult process, and the Société Industrielle d'Aluminium at St. Michel

makes 5,000 pounds with 4,000 horse-power by the Hall process. In Switzerland the Aluminum Industrie Aktien Gesellschaft, at Neuhausen, makes 5,000 pounds a day with 4,000 horse-power by the Heroult process. The demand for aluminum in the United States has lately been largely increased by purchases for Japan, and it is not unlikely that Europe will shortly be subjected to an inundation of Japanese art work in this metal.

The seven works at present producing aluminum are using either the Hall or the Heroult process. There have recently been hints in one of the papers devoted to the interests of this metal of a possible combination of the various producing firms for regulation of the output and the price. The current price quoted for the best grade aluminum in England is 33·2 cents per pound. A recently published estimate of the cost of production by Roberts-Austen was 27·2 cents per pound, of which only 2·2 cents is for electrical energy, while 12 cents is for the raw material of the manufacture. Becker, the former manager of the aluminum works at St. Michel, has published in his paper, *L'Industrie Electro-chimique*, a method of reducing this latter item by substitution of calcined bauxite, at 1 cent a pound, for the refined alumina generally used. Since 2·2 pounds of this calcined bauxite would suffice to produce 1 pound of the metal, it follows that such a substitution would reduce the cost of aluminum by 9·8 cents per pound. The aluminum produced, however, would contain about 6 per cent. silicon and iron as impurities; and in order to obtain from it high-grade aluminum, Becker would refine it by a wet process with which he is at present experimenting.

Minet's process for the production of aluminum, which was worked at St. Michel by Messrs. Bernard Brothers, of Paris, from 1890 to 1894, when it was displaced by Hall's process, has recently been further experimented with at St. Michel. The process consists in the electrolysis of a fused mixture of aluminum fluoride and common salt, and it is said that a pressure of only 3 volts is required to effect the separation of the aluminum from this electrolyte.

Blackmore, of New York, has suggested the use of aluminum sulphide, manufactured by a cheapened method, in place of the oxide. Kershaw has examined this proposal, and shown that it would not effect any reduction in the cost of the metal. Blackmore has also described a metallurgical method for producing aluminum which is more promising. Molten iron in shot form is allowed to descend through aluminum sulphide dissolved in molten fluorides of the alkali metals; the aluminum sulphide is robbed of its sulphur by the iron, and molten aluminum collects at the bottom of the vessel. Blackmore states that this process has been tried on an experimental scale with satisfactory results; but no details of the purity of the aluminum obtained by it have yet been published.

The influence of small amounts of carbon upon the physical properties of iron is so remarkable that it is interesting to note that repeated attempts have been made to obtain aluminum with a small percentage of it as carbide. The difficulty has been to get the carbide formed at temperatures below that of the electric arc. Dr. Roman has, however, patented a method for effecting the combination indirectly by means of calcium carbide. The aluminum and calcium carbide are melted together in the required proportions, and in this way the carbon is transferred to the aluminum at a comparatively low temper-

ature. Aluminum containing from 0·1 per cent. to 1·5 per cent. carbon has been produced by this method, and this is said to possess great elasticity and hardness. Dr. Roman has also patented an alloy of aluminum containing 1 per cent. nickel and 1 per cent. wolfram, which possesses the color of pure aluminum, but has much greater tensile strength and takes a finer polish.

COMMITTEE ON SCIENCE AND THE ARTS.

[Abstract of proceedings of the stated meeting held June 1, 1898.]

PROF. L. F. RONDINELLA in the chair.

The following reports were adopted:

Hard-drawn Copper Wire.—Thomas B. Doolittle, Branford, Conn.

ABSTRACT.—The report refers to the fact that Mr. Doolittle, in the year 1877, suggested the use of hard-drawn copper wire for telephone and telegraph uses, and in the same year, at the works of the Ansonia Brass and Copper Company, Ansonia, Conn., succeeded, after many experiments, in producing about 500 pounds of this material, which was employed on a telephone line connecting these works.

This method consists in using drawing-plates containing a larger number of holes than the ordinary plates used in copper wire drawing, and increasing the number of passes for a given reduction of area. By this means it is possible to draw copper wire from the beginning to the end of the operation without any annealing, and at the same time to avoid the crystallizing of the metal. The wire thus produced is sufficiently flexible to permit of the formation of standard telegraph wire joints without breaking or cracking.

The hard-drawn copper wire made by the Doolittle method has its tensile strength doubled and its elongation reduced to about 1 per cent., while its electrical conductivity is not materially impaired.

The report dwells upon the great utility of such hard-drawn copper wire for aërial conductors on account of its high conductivity and great tensile strength and reliability in prolonged service, which were amply demonstrated by Mr. Doolittle in his efforts to secure its adoption by the electric line builders; and it was due entirely to his persistent endeavors that hard-drawn copper wire was, at length, adopted for telegraph and long-distance telephone purposes.

Hard-drawn copper wire has now become a staple article of manufacture, not less than 8,000,000 pounds having been produced in the United States alone, in 1896. It is now frequently employed for all kinds of electric conductors, and especially for long-distance telephone lines, the successful operation of which, the committee of investigation admits, is in large measure due to its introduction.

The report concludes that Mr. Doolittle is entitled to recognition:

(1) For having been the first to recognize the value of hard-drawn copper wire; and for having, by his persistent endeavors, in the face of adverse conditions, succeeded in establishing its use for electric conducting wires; and

(2) For his long-continued experiments and labor in overcoming the many

difficulties encountered in producing, on the commercial scale, a hard-drawn copper wire suitable for electric conducting wires.

The Edward Longstreth Medal of Merit is awarded to Mr. Doolittle. [*Sub-Committee.*—Charles James, Chairman; D. Anson Partridge, Tinius Olsen, Clayton W. Pike.]

Expert Testimony.—[Investigation ordered by the committee.]

ABSTRACT.—Under-mentioned sub-committee was instructed to investigate and report upon the question of the propriety of sub-committees accepting outside expert evidence, and the extent to which such evidence may be accepted by sub-committees in reaching their conclusions.

The opinion is expressed in the report that the question of accepting expert testimony must, in each case, be left to the discretion of the investigating committee, subject, of course, to the revision of the general committee. It is suggested that any sub-committee basing its report upon outside expert testimony should state that fact. [*Sub-Committee.*—H. R. Heyl, Chairman; G. Morgan Eldridge, Theo. D. Rand.]

Rotary Motor.—Paul J. Reid, Philadelphia, Pa.

ABSTRACT.—The applicant submitted drawings of his scheme for such a device, and asked for an opinion as to its practicability. The sub-committee conferred with applicant and gave him the desired information. Report made advisory and case dismissed. [*Sub-Committee.*—H. W. Spangler, Chairman; Henry F. Colvin, J. M. Emanuel.]

System of Aërial Navigation.—H. H. Fisher, Corpus Christi, Texas.

ABSTRACT.—Applicant submits several sketches exhibiting his plans, a model and a number of explanatory letters, and requests an opinion as to the merits of the system. [The novel features of the plan, being unpatented, are communicated confidentially, and no disclosure of the same is desired.]

The report gives the applicant the information desired. [*Sub-Committee.*—Spencer Fullerton, Chairman; Henrik V. Loss, O. Chanute, A. F. Zahm, A. M. Herring.]

Pneumatic Balance Lock.—Chauncy N. Dutton, New York.

ABSTRACT.—This investigation relates to certain improvements on pneumatic locks devised by applicant. The committee of investigation bases its report upon an examination of U. S. Letters-Patent No. 457,528 and No. 557,566, and on the written description, illustrated by a number of drawings, of the proposed locks at Lockport, N. Y., submitted by the inventor.

[This description, with illustrations of details, will appear in full in the *Journal* in the near future, and reference is accordingly made to that publication, as without illustrations an abstract would not be intelligible.]

The sub-committee's investigation was limited to the consideration of (*a*) the general principles involved in the invention proper and in the principal auxiliary devices, and (*b*) the apparent merits of the scheme as a whole.

The sub-committee finds the following meritorious features in the type of lift-lock under consideration:

(1) The favorable manner in which the locks are supported, namely, by an elastic air-cushion over their entire base, instead of the local concentration of their weight at one or more points, as in the method heretofore used or proposed.

(2) The fact that no dry-dock is needed at the lower level.

(3) The "parallel-motion" device for ensuring horizontal alignment under eccentric loading.

(4) Security in case of accidents of even so serious a nature as the sinking of a loaded boat at one end of the lock, or the carrying away of the outboard gate by an incoming vessel.

An uneconomical feature of this lock is the great depth and size of the pit required for the caisson in its lowest position.

The report finds that the invention, as a whole and in detail, gives evidence of much ingenuity and careful study on the part of its originator, and is of decided merit. [*Sub-Committee.*—Edgar Marburg, Chairman; H. W. Spangler, Wilfred Lewis.]

Franklin Institute Gold Medal. (Referred by the Board of Managers.)

At its meeting of June 9, 1897, the Board of Managers referred to this committee the question of the expediency of establishing a special award of honor, in the form of a gold medal, to be given annually by the Franklin Institute.

The report gives a brief historical reference to a number of awards of specially honorable significance, established by a number of learned societies of Europe and America, and which have for their object, generally, "the recognition of eminent services in the domain of science, which directly or indirectly contribute to the advancement of commerce, arts and manufactures; or, broadly speaking, to the promotion of the material welfare of mankind." A number of these are specified and commented upon.

The special committee charged with the consideration of the subject expressed the opinion that "a grand medal of gold, which would be associated with the name of Franklin, could, with much propriety, be established by the Franklin Institute, as a token of its appreciation of works of national or international value," and that, with the proper safeguards which could be provided, such an award should take rank with the distinguished awards referred to in the report.

The report, therefore, recommends "that it would be advisable for the Franklin Institute to award, at each of its annual meetings, a grand gold medal, to be known as the 'Franklin Medal,' to the inventor or discoverer, whose work has, within the previous five years, signally promoted the arts and manufactures." [*Sub-Committee.*—L. F. Rondinella, Chairman; Samuel Sartain, Wm. M. Barr, Wm. H. Wahl, L. E. Levy, Edgar Marburg, C. J. Reed.

W.